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IMPROVEMENT OF MEN'S UNDERWEAR DESIGN PROCESS

Scientific specialty 05.19.04 – Technology of garments

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CONTENT

GENERAL DESCRIPTION OF RESEARCH

The relevance of research. Men’s underwear, thanks to the emergence of new materials and significant function expansion, has become one of the most dynamical developing clothing type. The purpose of underwear (daily, sports, correctional/shaping, for various shows, etc.) affects the artistic design and material solutions. The main indicators were comfort and the anthropometric morphology of lower torso of the male body, which is impossible without morphology knowledge, possible directions of functional and aesthetic correction, the main directions of modern design, and the deformation of closed “shells” of textile materials.

Positive results for improving the design of knitwear were obtained in the studies of G.I. Surikova, O.S. Baldovkina, V.N. Filatova, G.P. Starkova, E.G. Andreeva, A.V. Novikova, Z.R. Ivanova, I.V. Tislenko. At present, the knowledge of foreign researchers bases require further men’s underwear development with new information and latest technical means. Body scanner, as a tool for measuring dimensional features, have already been used to develop national anthropometric programs in many countries (USA, UK, France, China, Mexico, etc.) and to improve the design process of body-clothing systems, in particular, in the works of Luo Yun, Li Yue (IGTA), I.A. Petrosova (MSUDT), Guo Mengna (IVGPU). Other directions in the improvement of the design process are the use of the methodology of sensory analysis of the “body-underwear” system, the results will humanize the decisions made and increase the clothing comfort, and transfer the actions of designer to virtual environment in which the designer can carry out virtual fittings and evaluate the quality of artistic design decisions before actual manufacture.

The research has been done in 2016–2018 at the Department of garment design at the Ivanovo State Polytechnic University under the state task No. 2.2425.2017 / 4.6 on the topic “**Software development for virtual design of static and dynamic systems “body-clothing” and virtual fitting of FashionNet**”. The work complies with the following paragraphs of the passport of a scientific specialty 05.19.04: 1. Development of the theoretical foundations and the establishment of general laws of designing clothing for typical and atypical bodies; 5. Improving assessment methods and designing clothing with specified consumer and technical-economic indicators.

The degree of problem elaboration . Until now, there is no universal method for designing men's underwear. Due to the delicacy of the design subject, many aspects have not yet been studied and systematized. Especially often problems arise when designing correctional underwear to change the shape of the soft tissues of the bodies and when it is necessary to coordinate the properties of the materials with the size and number of details of the structure. Until now, the main indicator of physicomechanical properties when selecting materials is their extensibility, which determines membership in a particular group, however, it is impossible to predict a compression (push-up) effect. In the existing list of dimensional signs (size), only basic girths are included, which are clearly insufficient for underwear design with multidirectional directed contour lines. It is obvious that all of these aspects – the lower part of male bodies, knitted materials, the underwear structure, the consumer's sense of wearing – should be considered from the standpoint of expanding the functions of underwear and ensuring its comfort.

Keywords: male body, correction, underwear, knitted materials, design, construction, pressure.

The aim of research is to improve the design process of men’s underwear.

The main stages of research. To achieve the goal solved the following tasks:

- perform an artistic and constructive analysis of modern models of men's underwear to establish the boundaries of the possible locations of their contour lines, and lines of internal division on the surface of the lower part of the bodies;

– to conduct expert surveys of underwear consumers based on different anthropological types from different countries in order to determine a list of issues that need to be addressed during design;

– to carry out studies on the physicomechanical properties of knitted materials under conditions that are as identical as possible to those corresponding to their stressed state in real underwear;

– to study the mechanism of occurrence of compression pressure on the soft tissue of the bodies under closed tensioned textile shells under the conditions of their uniaxial tension and shear;

– to establish reasonable/accpetable pressure and soft tissue deformation limits, which can be achieved by correcting underwear;

– to develop a new index of the compressive performance of knitted materials and the method of their choice for men's underwear;

– to conduct anthropometric studies of male bodies were carried out in two states – in statics and after forced deformation of the soft tissues of the lower torso;

– to develop the classification of the lower parts of male bodies and the nomenclature from the traditional and new dimensional features for the design underwear structural drawings;

– develop a new design for men's underwear;

– to test the design of men's underwear in the ClO 3D computer environment using digital twins, knitted materials, underwear and avatar - underwear systems;

– to conduct industrial testing of the developed recommendations.

The objects of study – male bodies of different anthropological types, men's underwear, knitted materials, real and virtual “body (avatar) - underwear” systems, the process of designing and virtual simulation.

The subject of study – the process of designing men’s underwear.

Methods and means of research. We used VITUS Smart XXL body scanner with Athroscan 2014 program (Human Solutions, Germany) as a means of research of real bodies and “body - clothing” system, knitted materials mechanical tests – Kawabata Evaluation System KES (Japan), clothing pressure measurement on the surface of the body – FlexForce sensor (USA) with a computer program for recording results and ClO 3D virtual. For processing results of measurements used the methods of mathematical statistics, correlation and regression analysis (Excel, SSPS). Expert methods (survey method) were used to establish consumer preferences and to assess the feeling of the wearers.

The scientific novelty of this research is to establish a plasticity mechanism that affects the soft tissues of male lower body under the influence of the underwear design and the compression properties of knitted materials.

The following scientific results were obtained for the first time.

1. The relationship between the uniaxial tensile properties of knitted materials and the pressure they exert on the soft tissues of male bodies is established, and equations for predicting the pressure values are obtained.

2. A nomenclature of new dimensional features has been developed for describing the lower part of male bodies and their typical sections in the middle sagittal-plane have been obtained.

3. Established typological boundaries of changes in the male bodies plasticity under the influence of the complex effect of index of material properties and design of underwear to obtain the effects of push-up.

4. A new classification of the lower parts of male bodies has been developed, based on a set of new dimensional features necessary and sufficient for constructure drawing of underwear design and checking its comfort.

Provisions for the defense.

1. Classification of the lower torso of male bodies.

2. Method of determining the compression performance of knitted materials.

3. The method of constructing men's compression underwear.

4. The algorithm of virtual fittings using digital deformable twins of bodies, knitted materials in the stretched state and underwear, allowing to identify the stress state of materials and compression of the soft tissues of the body.

The theoretical significance of research includes the developed application of graphic-analytical method for flattening of knitted men's underwear by using new combination of body measurements to guarantee desirable compression of soft tissue.

The practical significance of research is consists in justification of the graphic method of constructing a expanded view of men's underwear from knitted materials using new sets of dimensional characteristics to guarantee the appearance of the necessary compression pressure of underwear on the soft tissues of the body.

The reliability of the results and conclusions provided by the combination of actual experimental and theoretical research results, the statistical sufficiency of the resulting equations, the use of modern measuring instruments and verification methods.

Approbation of the results. The results of the work were reported and received a positive assessment at the following conferences: the conference of young scientists, graduate students and students “POISK” (**Ivanovo**, 2015); all-Russian scientific student conference (**Moscow**, MGUDT, 2015, 2016); international conferences AUTEX world textile conference (Bursa, **Turkey**, 2014; Bucharest, **Romania**, 2015; Ljubljana, **Slovenia**; 2016, Corfu, **Greece**; 2017, Istanbul, **Turkey**, 2018); international scientific and technical conference (Vitebsk, **Belarus**, 2015); 45 international conference on computers & industrial engineering (Muse, **France**, 2015); information environment of the university (**Ivanovo**, 2016); international conference Aegean international textile and advanced engineering conference AITAE 2018 (Mytilene, Lesvos, **Greece**, 2018); 2018 3rd international conference on computational modeling, simulation and applied mathematics (Wuhan, **China**, 2018).

The main results of the work were published in 25 papers, including 6 articles in Russian journals from the list of the Higher Attestation Commission (ВАК), 6 articles in English-language journals included in the Web of Science database, 14 abstracts and conference materials, the total volume of which is 6.93 п.л. (personal contribution 3.63 п.л.).

The structure of the thesis. The thesis consists of 5 chapters, set out on 264 pages, includes 29 tables, 107 figures, 7 appendixes, 304 literary sources.

List of aberrations

$Abd._D$	–	Distance from the front abdomen to back vertical guideline
BR	–	Distance from the natural waist to crotch level
BPB	–	Basic pattern block
BH	–	Back point close to sacrum or coccyx in the hip level, not on the buttocks
Cr	–	Crotch point at bottom of lower torso
Cr_H	–	Crotch level height
CrL	–	Crotch level
CL_F	–	Front crotch length, from *WF* front to *Cr* across the genitals peak
CL_B	–	Back crotch length from *Cr* to *WB* through the hip middle groove
Cr_{SL}	–	Side length from the waist to crotch level, leg inside minus outside length
CP	–	Knitted fabric compression performance index
D_{FL}	–	Length from waist to ankle level in front
D_{SL}	–	Length from waist to ankle level in side
E	–	Ease of the material
$E_{\max}$	–	Maximum ease of the material
E_{warp}	–	Maximum ease ease) of the material elongated in warp direction
E_{weft}	–	Elongation (ease) of the material elongated in weft direction
EMT	–	KES index, elongation at 500 cN / cm load
F	–	Force (load) of tension
FH	–	Front point at the hip level
F(x)	–	Force (load) in different material elongation
G	–	KES index, shear rigidity (between shear angles ± 0.5 to ± 2.5°)
GL	–	Level of the front genitalia peak
GF_H	–	Height of genitals peak follow the wearing habits
GF_D	–	Distance from the genitals bulge peak to back vertical guideline
HL	–	Buttock level
H_G	–	Hip girth
H_H	–	Hip heigh
HB_D	–	Distance from the hip peak to back vertical guideline
H_{SL}	–	Side length from natural waist to hip level close to the body
$h_G = GF_H - Cr_H$	–	Difference between the genitalia peak and crotch level
$h_H = H_H - Cr_H$	–	Difference between the hip and the crotch level
$h_T = Cr_H - T_H$	–	Difference between the crotch and new thigh level, underwear bottom

$h_W = W_H$ - NW_H	–	Difference between the the natural waist to waistband level
$K_{компр}$	–	The compression ratio of knitted material (Тисленко)
KES-FB1	–	Kawabata evaluation system (tensile strain and shear properties)
KES-FB3	–	Kawabata evaluation system (compressibility and thickness properties)
KES-FB4	–	Kawabata evaluation system (surface properties)
LC	–	KES index, linearity of compression
LT	–	KES index, tensile rigidity
MIU	–	KES index, mean frictional coefficient
MMD	–	KES index, fluctuation of mean frictional coefficient
$Nav._H$	–	Navel level height
NT_G	–	Thigh girth in horizontal
NT_G	–	Thigh girth in oblique
NW_G	–	Torso girth below waist level at waist level
NW_H	–	Waistband height
P	–	Pressure
P_{body}	–	The maximum pressure measured on body
$P_{\max}$	–	The maximum pressure measured on material elongated
$Q_{1\ldots3}$	–	Quartile in descriptive statistics
RC	–	KES index, recoverability of compression
RT	–	KES index, tensile resilience
R	–	*r*, correlation coefficient
R^2	–	*R*-Square, coefficient of determination
$\overline{R}^2$	–	Adjusted *R*-Square
Sig.	–	Statistical hypothesis testing
S (M, L)		Size of body and underwear, small (middle, large)
S.D.	–	Standard deviation
SMD	–	KES index, surface roughness
$T_{1\ldots18}$	–	Textile materials
T_0	–	Material thickness under the pressure 0.5 cN/cm^2
T_m	–	Material thickness under the pressure 50 cN/cm^2
TL	–	Thigh level
T_G	–	Thigh girth
T_{SL}	–	Side length from natural waist to thigh level
WL	–	Waistline level
W_G	–	Waist girth
W_H	–	Waist height

WB_D	–	Distance from concave waist back to back vertical guideline
WC	–	KES index, work of compression
WT	–	KES index, tensile energy
e	–	Natural base approx. 2.718
δ	–	Actual relative error
ΔE	–	Knitted material after stretched from 10cm to a reasonable range
$\Delta B = CL_B - BR$	–	Value describing buttocks bulge (the difference between the profile section arc through the back and the distance between the waist level and the crotch to characterize the bulge of the back part)
$\Delta F = CL_F - BR$	–	Value describing genitalia bulge (the difference between the profile section arc through the front and the distance between the waist level and the crotch to characterize the bulge of the genitalia part)
$\Delta GW = GF_D - Abd._D$	–	Difference between waist front and the genitalia bulge
$\Delta WH = WB_D - HB_D$	–	Difference between hip and the natural waist back
$\Delta(W_H - H_H)$	–	Vertical distance from natural waist to hip level
$\Delta(H_G - W_G)$	–	Difference between hip and natural waist girth
2HG	–	KES index, elasticity for minute shear
2HG5	–	KES index, elasticity for large shear

Chapter 1. REVIEW OF MODERN DESIGN OF MEN’S UNDERWEAR

Underwear as one of the necessary clothing experienced a long period of development to form the current shape. When the early people change dressing from “skirt” type of the lower clothing to the underwear, they found that underwear changed people’s way of life, so that labour becomes more convenient and fast [192]. So the structure of underwear design reflects the beauty and functional has a decisive role in the human body wearing effects and comfort [190].

In the early times, the underwear are called “undergarment”, “underpants” or “underclothes” in some of the European literature. In the early 18th century, before the European Industrial Revolution began, men’s underwear are mostly as “loincloth”. Furthermore, Europe, Asia and Africa men’s underwear have a wide variety; there is no fixed style structure, no similar to today’s mass production of daily underwear. To the 19th century, “John’s boxing underwear” (tight-fitting pants) began to sweep, began to have the shape of contemporary underwear. Then into the 20th century, men’s underwear varieties began to increase, can add apply the concept of design to men’s underwear.

Nowadays, with the improvement of the living level and the growing consciousness of their health, the comfort and individuation of underwear have expanded beyond the traditional requirement [85], and the consumption of the male’s underwear consumer market has become more prominent [110]. At present market has a wide variety of men’s underwear with a lot of different styles and performance products, and the manufacturers also distribute around the world. So men’s underwear with a good potential and development prospects is a branch of the Chinese garment industry. Moreover, the design of contemporary men’s underwear is towards comfort, fashion, personalised direction, structural design of science and technology to promote the development of the underwear are more scientific and reasonable [249]. Different from the women's underwear, men's underwear mainly dominated by briefs, boxers etc.

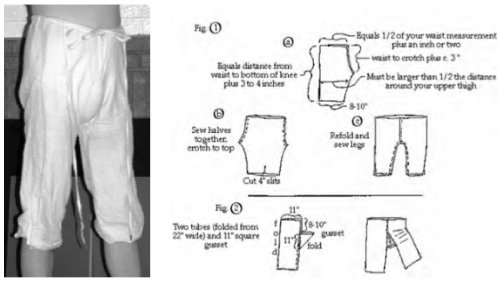
Contemporary men's underwear is no longer a part of daily basic concept of cover-up, warm in the traditional, but shaping and personalizing towards more design concepts, which shows male charm and masculinity. Men's underwear had towards to more visually and functionally [111], in the style of design, is increasingly focusing on the characteristics of the male body movement, such as the favourite type of push-up effect boxers in internationally, it is more suitable for sports [189]. Now, more and more males began to pay attention to the beauty of underwear and the physical beauty after wearing, so men's underwear also use shaping – push-up effect as design features to meet male aesthetic and physiological needs. However, few men's underwear in the China markets could meet the requirements of this feature or only meet some shaping but neglected comfort requirements. Therefore, based on the development trend of men's underwear in China and international market, to study on new reasonable comfort men's underwear design is imperative.

1.1. Brief history of underwear

1.1.1. Types of men's underwear

In the time old age, the "Loincloth" was born seven thousand years ago [76]. The Medieval "Braies" are a type of trouser worn by Celtic and Germanic tribes in antiquity and by Europeans subsequently into the Medieval [79]. The union suit is a type of long one-piece underwear that was created in Utica, New York around the 19th century [78]. Long "Johns" were first introduced into England in the 17th century, but they did not become popular as sleepwear until the 18th century [77]. Kneibler A. first designed the Y fronts design in 1934, Kneibler introduced a new kind of snug, legless underwear with an overlapping Y-front fly [74].

a



b

c

d

e

Figure 1.1 – The old age of underwear: a – Loincloth; b – Braies; c – a union suit from the 1902, Roebuck catalogue; d – John L.S. and Long “Johns”; e – Y fronts and Jockey shorts

Contemporary styles of men’s underwear are gradually developing and growing, and it has become one of the fastest innovation parts in men’s clothing market [68]. Kinds of men’s underwear are including different garments that are depending on its functions and application (daily, sports, shaping, *etc*.). Consumer demands are covering many aspects such as the market responsibility, brand, uniqueness of underwear [64], and the possibility of individual customisation for own body morphology [148]. Namely, the wear comfort has taken the priority [9].

Underwear may also provide warmth as an additional layer, and protect outerwear garments from perspiration. For men, specifically, lower underwear function as a base layer to provide support for the anatomy of the lower torso.

This vibrant market is growing with a wide range of categories, including more than ten items, such as,

- **Boxer-Briefs**, tight-fitting Boxers, the structure similar to the Boxer-shorts but with a few long or long legs, it could added functional design;

- **Boxers** (Long Boxers or Midway-Briefs mostly the Jockey company manufactures), usually very tight-fitting and long legs, almost all have functional design;
- **Boxer-Shorts** (Trunks, such as daily basic underwear, swimming trunks or bathing trunks), loose-fitting or directly, long or short kinds types, usually have a fly in front, fabric is rarely stretchy (cotton), no functional design;
- **Briefs**, tight-fitting and basic type, like a “triangle”, without legs part, could add functional design;
- **Bikinis**, swim briefs;
- **Strings**, short than Briefs;
- **Thong** (G-string), as Briefs but at the back, the material is reduced to a minimum, almost always designed to cover the genitals, anus, and perineum, and leave part or most of the buttocks uncovered;
- **Jockstraps**, as a jock, jock strap, strap, supporter, or athletic supporter, for supporting the male genitalia during cycling, contact sports or other vigorous physical activity.

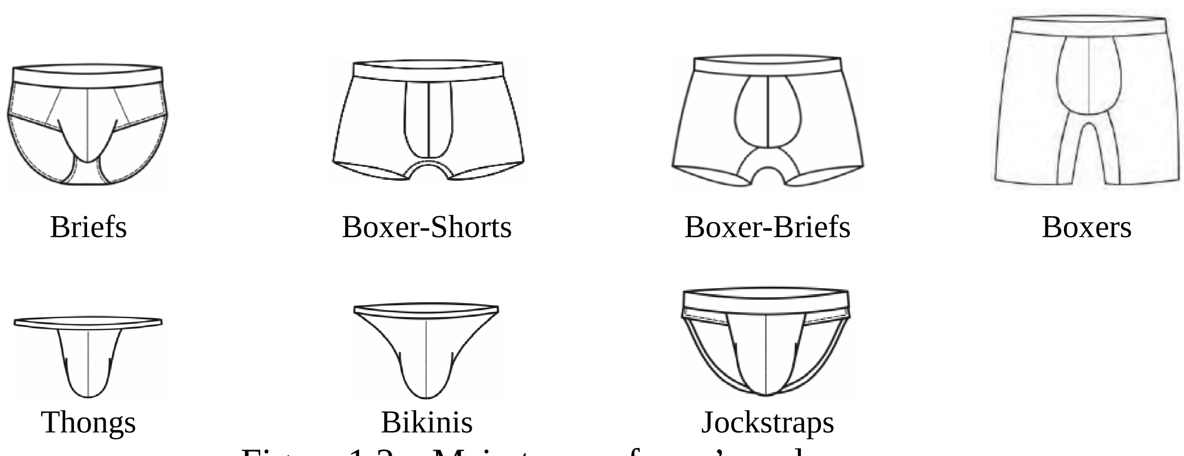


Figure 1.2 – Main types of men’s underwear

Compression tight-fitting (correction effect) underwear. It is a kind of a good design concept, comfort, structural stability, and tight-fitting underwear, this type of underwear in recent years become more and more popular.

Correction underwear focuses on the design of front pouch (pouch) part, mainly on the underwear front part functional changes, changing the primary insert type to the current “egg” shape of the pouch. For men’s underwear, front is a very special part, it needs to increase the compactness of fit with the genitals to enhance the comfort in dynamic and static. Crotch and back hip design – the crotch part design of the primary type underwear usually sew the front pouch bottom, front and back pieces to one inseam, which is similar to pants inseam, the process is relatively simple, but there is a lack of wearing comfort and fit, and it breaks easily. “Push-up” (lifting) effect, as early as the 16th century was applied to women’s corset, which modified the characteristics of women’s breasts. Moreover, now, the men have their new request appreciation of the beauty, so in the men’s underwear market, this functional concept is also popular in the underwear design. The “cup” (or egg shape, similar to the bra), mainly due to its unique structure, lift the genitals soft tissue (Figure 1.3a, b). People are trying to use the new design concept as much as possible to replace or surpass the old design; it can be said that this is men’s underwear market iconic developing process.

a b c

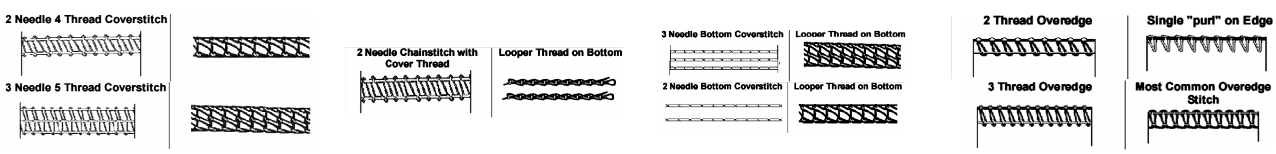
Figure 1.3 – Push-up effects in female bra and male underwear

Figure 1.4 shows underwear types are classified by waistband postion, such as (b) by height of waistband – high-rise, mid-rise and low-rise, in common, mid-rise below nature waist level is 4...10 cm, low-rise is below 10...20 cm. (c) the length of underwear compared with inseam and side seam length – boxer briefs, inseam is 0...3 cm, short Boxers is 6...8 cm and Midway Boxers is more than 8 cm (longer in the leg than boxer briefs and tighter-fitting), and side seam length is affected by position of the waistband, so we usually distinguish underwear from inseam length. (d) the briefs with different side length.

a b c d

Figure 1.4 – Underwear types, a – different waistband height and seam length, b – different waistband height, c – different inseam length, d – different outside length

The process of the front crotch and thigh bottom are usually used stitches of 2 (or 3) needles bottom cover stitch (looper threads on bottom) for panelling tripe and covering edge, 2 needles chain stitch with cover thread, 2 (or 3) needles 4 (or 5) threads cover stitch. The sideseam and inseam are usually used 2 (or 3) threads overedge stitch. Moreover, mostly only used 2 (or 3) needles 4 (or 5) threads cover stitch for whole seams of underwear sewing (Figure 1.5).



a b c d

Figure 1.5 – Sewing stitch of men's underwear (front and back)

Today, the new kinds of crotch part design in men's underwear is popular – the separate crotch piece, back sewed with the hip piece, usually as a curve line lower than hip level, the inseam moved to the front thigh, close to the thigh front middle. This kind of crotch piece design, not only increase the space of crotch but also decrease joint seams by many pieces in the inseam, so that the bottom of the crotch is more complete, and not easy to break; add the structure line in the hip to change the structure to increase the hip soft tissue pressure and lifting. The effect of lifting on the genitals and hips are mainly obtained through the structural design or knitted fabric properties on the soft tissue (similar to women shaping clothing).

Men's tight-fitting functional underwear can not only through the structural design, but also through the special properties of knitted fabric to achieve the function [140]. The function of "push-up" on men's underwear is wider applied to sports underwear, due to the obvious friction between genitals and inner thigh during movement. Therefore, it is necessary to adjust and strengthen support of the underwear crotch and genitals parts, to separate genitals from thighs, and finally provide better protective effect on the movement of the human body.

1.1.2 Existing research of men's underwear

It has been known for years that male genitals require special support and protection on rough activities [29]. However, some loose types of male underwear, for that it is no use in protection effect, can also a reaction to a man when after executing a certain move. Such as moving a thigh towards the abdomen and thus pushing the thigh against the testicles, bring forth the shock of a direct hit and abrasion [242]. Men's underwear generally has several deficiencies, including the conditions of the scrotum to contact and stick to the inner thigh and inappropriate pressure caused by pouch structural design can lead to friction, chaffing and discomfort while sitting, running or squatting and other numerous athletic activities.

A lack of support for the genitals, limit freedom of movement and natural resting position of the genitals, cause a lack of air and moisture permeability. Therefore, some types of underwear like “trunk”, “jockstrap” became popular. Male anatomy is quite complex and more than just the genitals, the lower abdomen and the buttocks are important. To avoid other inconveniences such as rounded abdomen which tends to push down the briefs, different size and wearing preference of genitals, other design elements in the briefs must be introduced.

(1) Appearance design of men’s underwear. With written records, some unique design concept of men’s underwear were for that period of underwear improved and do not have completely and scientific drawing step. For example: in 1936, M. Rumery [129] designed a separate pouch in front crotch, for male genital and thigh separation, support (lifting) and improve comfort, but it was only a simple pouch which similar to the triangle pocket. In 1938 F. Chatfield [17] designed the “U-type” pouch and had a fly opening in the upper part of the pouch (near the waistband), which was similar to today’s “Y-type” men’s underwear and has a separate rhombus bottom crotch piece. In 1965, C. Casey [33] designed a “lifting” underwear, but it is a mechanical lifting pouch, the lower part of the front pouch is openable “A type” design, the top buckle can be hung on the front waistband and adjust the tightness of the lifting. In 1970, J.S. Atlee [92] designed underwear to perform a function with the minimum discomfort and inconvenience by providing in the pouch. In 1979, H.G. Dietz [67] borrowed from the structure of the cup of female bra for men’s underwear pouch design, and the upper of the pouch had two directions straps like a bra, to give support and protection to the male genitals. In 1995, W. Brocks [214] designed “modern” underwear, and all the edges and seams have the elastic strips (panel), to prevent deformation. In 2011, R.S. Cutlip and W.T. Kitsch [158, 215] designed a “pear-shaped” pouch viewed from the front. A lower extremity of the pouch extends to perineum portion for covering the scrotum and perineum, increased comfort and wearability.

(2) Design of men’s underwear. In the underwear design, in addition to the fabric, underwear structure and ease design are also significant parts. Men’s underwear are unlike women’s underwear in the design, due to physiological characteristics in the genitals of the structural design largely determines the products comfort and functional. Except for the improvement of the front part structure, the transfer of the inseam and side seam has also become a key point for improving the wearing comfort.

(3) Scientific research of men’s underwear. A. Winifred [1] published a book “Metric Pattern Cutting for Menswear” (1990) involved men’s underwear pattern, but the number of samples is single and the specific drawing method is too simple, the pattern making method is point-to-point drawing. A. Haggar [63] compiled a system of women’s underwear and tight-fitting clothing book named “Pattern Cutting for Lingerie, Beachwear and Leisurewear” (2004), but there is no pattern design for men’s underwear.

In Asia, from 1940, Japanese underwear research and product developed significantly, and provide a useful technology platform for the Japanese domestic underwear enterprises. [264]. Nakazawa [139] completed the book tittled “The Human Body and Clothing: Structure of The Human Body, Elements of The Beauty, Pattern Block” (1996), and made a detailed analysis on the relationship between clothing and the human body, which provide significant help of theory support and structure design.

From 2004 to 2013, Y. Jianrong, C. Jianliang [231, pp.55-60], [230, pp.81-88], [16, pp.94-104], [229, pp.100-151] published four books on men’s and women’s underwear. Related to the underwear pattern blocks of grading and layout and the production process, which contains nearly ten men’s underwear blocks making the method and simple exposition of the technique. However, some of the steps are very vague, the use of the structural data are mostly measured from the finished underwear, and the human body data are too elder to be used to do the scientific design.

Therefore, it is not good for the beginners to learn. C. Yuehua [24, pp.165-170] published “Garment Pattern Block Design” (2007), this book is a comprehensive clothing design textbook, including men’s underwear structure design, simple and unique design method, which are suitable for beginners to learn. However, the data are inaccuracy and empirical, it is difficult to ensure that the underwear can be made to meet the human body. D. Pengju [37, pp.95-97] also published a book of “Underwear design” (2009), which contains one male underwear pattern block, the method is different from Y. Jianrong and C. Jianliang’s, but still cannot avoid the data vaguely. Then, C. Lifan*g* [15, pp.63-77] published “Underwear structure design and pattern block” (2013) which was written differently from other books and similar to A. Winifred’s method of point-to-point, straight line mostly forms the pattern block.

Since 2005, W. Chengfang, X. Fuping and Z. Tierui [200, pp.72-73], [224, pp.37-39], [244, pp.70-72] based on the version of the basic structure of men’s underwear, optimise and improve the crotch and hip detail section. Due to the investigation of the relevant research on men’s underwear structure, most of the underwear structure partial optimisation did not involve the innovation and design of the new pattern making method. To 2013, Z. Lixin [263, pp.113-119] studied on the male lower limb, he analysed the different structure and shape characteristics of male underwear and provided some reference for the structural design of underwear. T. Bonan [188, pp.12-20] studied the results of the comprehensive results of the subjective and objective evaluation and obtained the best comfortable parameters combination of the crotch structural for the middle-type body of young male college students: front pouch rise 2 cm, front crotch width 2.5 and back 4.5 cm or front pouch rise 1.5 cm, front crotch width 3 and back 4.5 cm determine comfortable value on the waist, hips and front crotch, and established the comfortable pressure perception model of underwear.

So far, the Chinese researchers which involved men’s underwear structure design are few and chaotic, most of the books can be found ten years ago, which cannot be very good to adapt to today’s design, production and teaching.

Men’s underwear towards to more visually and functionally, in the style of design, is increasingly focusing on the characteristics of the male body movement, such as the famous type of push-up effect boxers. [189]. Now, more and more male began to have pay attention to the visual beauty of underwear and the physical beauty, so men’s underwear also use “shaping” as design features to meet men aesthetic and physiological needs [254].

1.1.3. Modern markets of underwear productions

In China 70 to the 80th century, the most basic type of men’s underwear began to enter the market, no brand and sales in the large shopping malls [47]. Until 90th, Chinese men’s underwear market began to enter the stage of development. Chinese and foreign clothing industry began to trade exchanges, a large number of international brands enriched the men’s underwear color, decoration pattern and type, then underwear brand started to appear [268]. After 2000, men’s underwear functional, thermal underwear, health underwear began to sweep, the products began to be subdivided, different area different popularity types of underwear, moreover men’s underwear advertising began to appear. In 2009, the Chinese men’s underwear consumption expenditure survey found that 500...800 *yuan* per year, expenditure ratio reached 39%, 800...1500 *yuan* per year expenditure ratio reached 19.3%, and more than 1.500 *yuan* per year also have 11.6%. It is shows that people’s living conditions are improving, the excellent quality, and variety style of products have a lot of market space. Since 2010, men’s underwear personalisation, comfort began to be taken into account, thus, fashionable, branding as the central concept of competition, sales channels from standard store change into multi-network, television, speciality store, supermarkets and other means.

According to the “2015-2020 China underwear industry market demand forecast and investment strategic planning analysis report” pointed out that in more than ten years, China’s underwear industry has been gradually improved and mature. At present, China has a total of more than 3,000 underwear enterprises, while women’s underwear products occupy 60% of the underwear market share, the number of China’s annual sales of up to 300 million brains, and still 20...30% yearly growth rate.

International underwear industry developed rapidly in the past two decades, and a more substantial rate of growth each year. During the past decade, consumer demand for underwear has been growing on a global scale [167]. In 2014, only Chinese underwear market (include women’s and men’s underwear) consumption more than 20 billion dollars per year and an annual growth rate of nearly 20% [96], the men’s underwear market only occupied one-sixth of the women’s. Because of the design innovations of men’s underwear in the primary stage in China, branding, individuation, scientific design *etc*. are lack of development. Only a simple production, processing and sales model, and the production capacity compared to women’s underwear is just 1/6, with great of market development [48, 23].

Moreover, according to the data of “The 2010 China Sixth National Census” (2010) [25], male population accounted for 51.27%, about 690 million. The central purchasing power during 15...34-year-old, the male population accounts for approximately 15.47%, nearly 197 million people; female population accounts for approximately 15.21%, nearly 194 million people, we can see that male were significantly more than women. It can be seen that the potential importance of this enormous market.

Nevertheless, we can see some companies imitated the design of underwear from abroad in the market. Although the technological production level transparent, poor fabric material, but sales volume well, the reason is one low price. Another mainly because of its original good design sense and version of structural advantages, which brought a warning to the design of the traditional underwear industry, today’s men had not the indifferent attitude of underwear.

1.2. Modern underwear and the human body

The body’s overall skeletal structure is connected by a variety of joints, at the same time, the interval of movement of the joints also limited to the direction of specific movement of bone and movement. This is the first feature of the body. The bones, muscles and soft tissues growth and other changes, the result of the formation of a specific part of the deformation, known as the body’s second feature; with the various curvature of the body shape, the skin at a specific location to produce uneven expansion, so as to adapt to this deformation (such as the change in the skin of the hip while squatting and standing), which is called the body’s third feature. Eventually, these deformations will be affected on the tight-fitting underwear. To joint, the three body features to measure the deformation direction, and volume amount each part of the body, to seek the form of underwear which adapts to this change, structure, and fabric is the key to the design of underwear.

Over the years, due to the importance of underwear in people’s lives and the complexity of the lower torso of the human body, it is always the focus of clothing researchers and hot theoretical issues that how to make the underwear structural design more standardised, more in line with a variety of male body. Peoples’ wearing requirement gradually from the beauty to comfort, with this wearing concept changes, the professional research of underwear from the simple gradually extended to the complicated field.

From 1995, S. Shimin *et al.* [176] have studied and detailing described on the relationship between the body and the trend of the crotch, hip parts bending in pants pattern block, and the relationship between pants and body. Z. Guangyao [261, pp.57-

63] used clothing cutting method analysed on the pants deformation with some basic measurements, then got the corresponding relationship between the body and main parts of the pants, which provides a quantitative basis for the study of optimising the pants. Z. Wenbin [247, pp.58-94] explained the method of functional and variability structural of pants design with the difference between hip and waist girth, the calculation among the crotch area in the book of “Clothing technology”.

From 2001 to 2005, Z. Jiang [258, pp.10] studied the problem of adaptation in clothing design and body movement, analysed the movability and wearing comfortable from the perspective of human engineering. L. Kan *et al*. [118, pp.54-56) experimented the changes of human torso skin in different postural, and the relationship between these motion parameters of the human body and the ease value of clothing, so that makes the design of clothing can take into account the comfort and aesthetics. T. Jun [182, pp.7] studied on the change of body type and the ease, and the reference of the ease value of clothing was given according to the variation of human motion. X. Ping and Z. Xiaolei [211, pp.1-6], [256, pp.15] studied the dynamic changes of the male lower torso and the structure of tight-fitting pants. Meanwhile, involved some tight-fitting pants design elements, such as ease, fabric and structure.

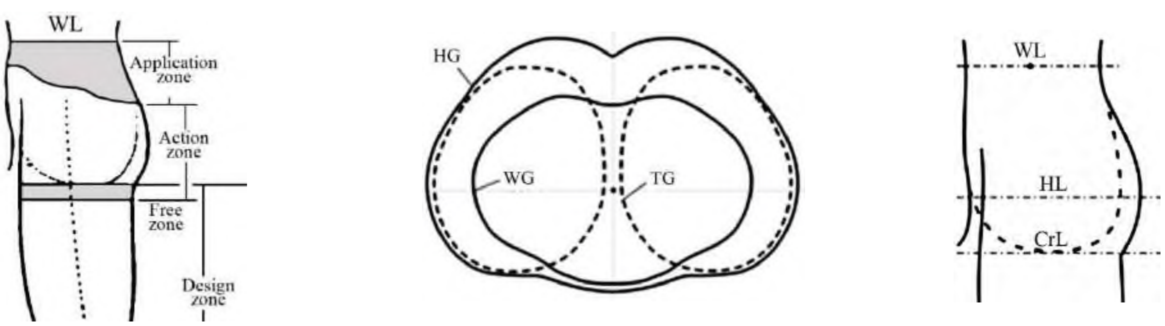
American scholars studied the skin elongation data of different parts of the body in different postures, which are often cited because of the necessary quantitative description of the elasticity of the clothes.

Japanese scholars began to study in this area earlier: in 1981 Koike [103, pp.94-110] used the gypsum method and the Moore contour method analysed of the lower limb movement caused by skin deformation. To 1996 Nakazawa [139, pp.62-66] studied from the perspective of the human anatomy, analysed the movement caused by the deformation in the design of the pants. In 2000, “The Clothing Department of Japan Ergonomics Research Society” [186, pp.95-111] was compiled by the “New clothes and the human body” in the use of fine line with the qualitative analysed of the significant joint movement on the skin deformation.

1.2.1. Anthropometric characteristic of the male lower body

Men’s underwear or pants structure research mainly focus on the human lower body shape – thighs, waist and buttocks (cingulum member inferior) parts *etc.*, the lower limbs are important to support the body with a wide range of movement. For the study of underwear structure, we can start from the prototype structure of short pants, combine with men’s underwear structure, focus on the characteristics of the male lower body, and analyze its structural characteristics and changes in the influencing factors.

In the structural design of pants, the lower body features of the human body are closely related to the wearing comfort. If the design is not reasonable, the movement of the wearer will be affected. Figure 1.6 shows the lower body function area distribution, body-fit area, motion area, and free area and design area. About the underwear structure, we need to study the body-fit and motion areas – the black area (from waist level, iliac crest to upper hips) (Figure 1.6a); motion area – from the front abdomen, trochanter parts, hips and thighs to crotch level; free area – from gluteal groove, crotch to below. The most intimate, complex connections are “waist-hip-thigh” with different morphological characteristics. It can be seen from the body centreline of cross-sections (Figure 1.6, b), the proportion distribution of waist front and back are balanced, but the volume of hip back is more significant than the front.



a b c

Figure 1.6 – Shape of waist-hip-thigh, a – area of lower limbs, b – cross-section, c – profile of body [139]

The movement of body joints will cause the skin deformation in horizontal and vertical directions, the deformation values can guide the shape and ease clothing design [237]. At present, scholars have studied more skin deformation in dynamic condition. As we know, human skin can be extended from 20 to 200% due to physical movement. Y. Sumiko [178] analysed the specific requirements of clothing of the various sports changes in the book of “Clothing typology” (1976). In 1980, A. Yoshio [234], [235] announced the skin surface stretch rate during exercise, the data on the joints of the human body were essential reference values for how to consider the changes in clothing structure under different clothing ease and movement. In 1983, Japan’s D. Tanaka [40] said the different age, the body skin deformation under the same tensile stress are different. W. Weiping [206] studied the structure of the pants and measured the dynamics skin changes of the lower body. W. Yanzhen (2013) [208] tested the lower part of body skin deform about ± 7.00% in horizontal and -60.00...40.00% in vertical while running. W. Tingyan [247, pp.45-49] tested the lower part skin body while running, the waist (abdomen) and hip change range is -48.00...36.00%. Z. Li (2016) [218, 255] studied on skin tension with -15.08...24.22% in horizontal and -20.54...26.48% in 90° lifting legs and squatting.

It has been found through some skin stretching experiments that skin deformations are different for each region of the lower limbs for some routine or exercise. In the walking or running activities – the areas with the most changes mainly concentrated on the thigh and knee, in the squatting – the maximum changes (extension) occur in the front knees and buttocks, and shrinkage in the abdomen and front thighs (groins).

1.2.2. Measurement used to design underwear and pants

Nowadays, the classifications of body type is usually based on the whole body features. Chinese types of Y (slim), A (typical to slim), B (typical to overweight), C (overweight) conform to the difference of bust and waist girth [144]; Japanese 7 types of Y, YA, A, AB, B, BE [27]; European (France, Germany *etc*.) types of 38, 40...62, the body measurements are more extensive than Asian people in the same type level. Most countries in the world have their standard sizes, but they differ in size due to their geographical, economic and political differences [50]. Comparison of the primary dimensions: waist circumference, hip circumference and chest circumference, the size of the measurements is the basis on body size differences, and the difference between the different degrees of the best reflects the body shape characteristics. Especially France and Germany, the sizes between the German 40 type and the French 40 type are significant different. Although bust(92cm) are the same, but the hip of German 40 type (100 cm) is same as the French 42 types, the waist of Germany 40 type (76 cm) corresponds to France 44 type waist (76.2 cm), as well as Italy, Spain, Britain and other countries' size. [34]. Because the traditional classification of underwear based on the value of waist girth and height are not unsuited for describing the details of particular parts, like genitals and hip bulge. From our questionnaire we could know, some people's underwear cannot fit their body even with the right body type in traditional size (height/weight or height/waist) showed in the labels on the packaging.

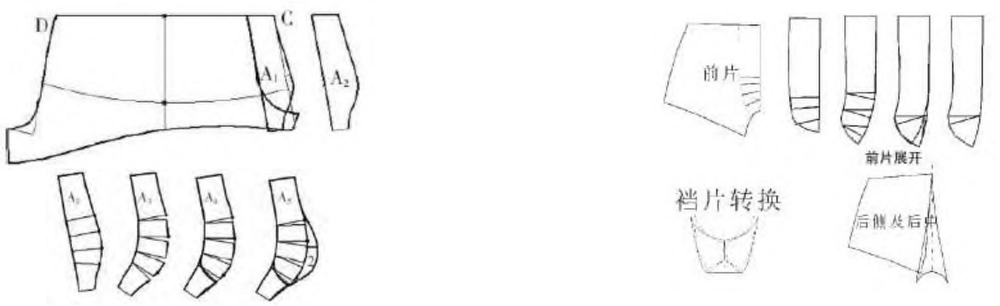
Clothing size is usually marked like S, M... or 170/88A, men's underwear size is also marked/designed on the base of traditional-using measurements (such as waist, weight or height) and labeling as S, M or 170/95, *etc*. The schedule doesn't have some crucial measurements of male bodies that reflects the bodies' morphology [104], different regions have different categories of underwear, but the general method of pattern block drafting is similar [151]. Sometimes the size charts are different between brands and styles, including different geographic traditions [72].

Moreover, the similar ways of underwear identifications and male body classifications cannot explain the clothing features and different styles [169]. The consumers with distinctive physiological characteristics and different body measurements should use one size chart [133]. Underwear cannot be try on before purchasing to control the fit and the comfort. The consumer needs more information about specific features and construction of underwear to be confident about wearing comfort.

In 2006, Zou Ping [270, 271] analysed the hip, crotch width and body rise of the lower torso of the human body, and added the ease value to the structural design of the trousers. Yang Nian [225] discussed the dimensions of the waist, hip, hip girth minus crotch girth of the male body, and added the ease to design of men's tight shorts. In 2008, GAO Yiwen [58] took the vertical measurements of the lower torso – body rise and perineum height account into pants pattern block design. Zhang Cuihua [240] studied the local size of the human lower torso (crotch length and width etc.) and compared with the results calculated by the formula based on the 3D design. Petrova A. [147] measured 24 subjects 12 measurements on lower torso parts, defined them into 3 body shape groups (straight, medium, curvy) determined by the hip-to-waist circumferences ratio. Chen Y. [20] selected 6 measurements from 21 bodies, and obtained the fuzzy models, so that ease can be calculated and the method has been validated in the design of 3 types of trousers. Zhang Zhongqi [253] analysed 49 dimensions and 5 variables of men in the western Chinese region,the results showed that the two indexes of hip - waist difference and waist height/waist girth could be used to classify into 5 kinds of human body shapes (lower body). Zhang Tierui [243] optimised back hip part of men's underwear, to make it fit hips, and used traditional body measurements – waist girth, crotch length.

In 2010, Hu Xiujuan [81] measured 4 measurements (waist, hip girths and crotch length) of 50 athletes under erect-standing state and riding state, and the appropriate structural design of seamless riding sports wears is completed. Liu Dong

[117] analysed on the hip girth, back buttock slope degree, and the method to design crotch part of the shorts has been obtained. Zhang Yanhong [250] studied the structure of the body rise, crotch width and hip girth, and different hip bulge types, three types of pant back pieces have been designed. Chen Mingyan [19] analysed 16 dimensions based on body measurements of waist and hip girths, body rise, hip minus waist. Zhou Shaohua [260] adjusted the front width, back width, body rise and inseam length, then analysed crotch structure. Wang Chengze [199] studied the new measurements of 3 angles in profile, the structure of the original underwear was optimised. Song H.K. [170, 171] used waist, hip and thigh girths, waist to crotch length, and inseam length to optimise the industry pants pattern block. Feng Feng [52] (Figure 1.7a) used body measurements of height, waist girth, crotch length to optimised the front pouch piece based on original underwear pattern block. Su Zhaowei [177] (Figure 1.7 b) studied the distance of waist to hip and crotch width of the male body, and optimised the men's underwear front pouch of the panties through the structure of the existing men's underwear in the market.



a b

Figure 1.7 – Optimize of underwear pattern block: a – optimize of the front pouch; b – optimize of the front and crotch pieces

To 2011, Lu Pan [125] measured 13 measurements (such as waist, hip, belly girths, body rise, waist to hip etc.) of 121 bodies, and used different ease on the waist and hip levels to made eight pants samples for wearing feeling test. Wang Gehui [201] obtained the pattern with zero ease (tight-fitting) trousers through the experimental correction of crotch width, buttock angle, body rise, crotch length. Gao

Lei [57] researched about 22 measurements on the male lower body on waist, belly, hip and thigh parts, used girths and heights of the waist, hip, body rise and crotch width to adjust men's underwear based on original pattern blocks.

From 2013 to now, Sun Jingjing [179] calculated the size of the human body for structural design based on the human body neck, bust, waist and hip parts. Cao Bin [13] studied the hip girth, and crotch width of the Central Chinese male body lower torsos, and the design of the pants structure was optimised, and the comparison of the fit is carried out. Xia Yan [226] studied five distances in hips and improved the pants pattern block with the ease, darts and back centre lines change. Zhuang Qian [265] studied data of lower torsos, divided hip into three kinds, and analysed five types of pants pattern blocks with different values in crotch part.

1.3. Modern technology for the study of comfort underwear

The comfort of clothing has become one of the leading characteristics of modern consumer demand [60], more and more attention to the contemporary male underwear fitness and comfort, because when wearing underwear, it will inevitably produce pressure [205]. The deformation process of fabric in the process continue to accumulate, resulting in elastic fabric ease, and not enough to provide the comfortable pressure to the human body. If the fabric can adapt to this deformation and recovery, it will make people feel comfortable; on the other hand, the fabric will hinder and bring some pressure to the body, and make people feel uncomfortable [59]. Therefore, the tensile properties of knitted underwear play an essential role in the functional and comfort of underwear [204, pp.24].

In recent years, the shaping men's underwear innovation are from two aspects: functional and apparent with the ergonomics and aesthetics development. Besides, the shaping underwear has become a hot research point in the medical application, mainly in postpartum body sculpting, health care and so on. Asian and European experts and scholars have studied the relatiships between dynamic/static pressure comfort and tight-fitting clothing (underwear, tight-fitting clothing, stockings *etc*.). In general, we use negative ease allowance in tight-fitting clothing design, and the value must be consistent with the fabric elongation and underwear function [106, pp.182]. While the typical type of men's underwear was based on simple structure design (tight fitted not enough), and produced a few pressure (not easy to measure) on the human body . So it's essential to study the compression underwear.

So far, most of the researchers used direct measurement to test tight-fitting underwear (pants or clothing) by the sensor, such as "AMI air-bladder" (Japan) and "FlexiForce A201 thin-film sensor" with "Wireless ELF System" (the United States) in Figure 1.8. However, the drawback of the direct measurement is that it only measure the pressure at a limited number of places. Moreover, for large injury surfaces, it is difficult for the sensor to access the wounded area, and the method of direct measurement on the human body is considered to be time-consuming and uneconomical [3]. The main reason for the associated time and cost is that the pressure garment needs to be constructed firstly to enable direct pressure measurement. Furthermore, it is also intrusive for the patient to cause discomfort. So, some new measurement (contact)/simulate prediction (non-contact) methods are proposed to overcome the problems.

Figure 1.8 – Pressure measurement instrument

The research on clothing pressure comfort can be traced back to 16th century, due to the emergence of female corsets, it cause severe wearing deformation displacement of the chest, stomach, and the restraint and shape of enormous devastation on the female body. At the end of the 18th century, the E.M. Crowther [28, pp.323-33] studied and found that long-term wearing of tight-fitting jeans will not only lead to physical deformation but also damage human health. In the 1930, the progress of human-made fibre technology revolutionised the material of the modified underwear. Especially with a flexible elastic band and rayon, it maintain the female body and will not cause harm to the body.

In 1972, M.J. Denton [38] had studied the relationship between pressure comfort under the static body and tight-fitting clothing with a maximum average pressure 2.68 kPa. Moreover, due to individual differences and different parts of the body, the body feels uncomfortable when clothing pressure is between 5.88...9.80 kPa, which is closed to the blood surface of the capillary blood pressure, the comfortable clothing pressure range is 1.19...3.19 kPa, this study data are now generally accepted and used. Since the 80s, J. Klöti [101] people began to pay attention to the clothing pressure positive influence on human body such as through pressure therapy for treatment of hypertrophic burn scar, prevent venous dilatation reduce the probability of thrombosis, congestion and blood circulation disorder [22, 174, 228]. H.P. Giele *et al.* [56] measured the cutaneous pressures generated by a pressure garment, the results show clothing over soft sites generate pressures ranging from 1.99 to 4.39 kPa, over bony prominences the pressures range from 6.27 to 11.99 kPa, the method should be used for more extensive research projects on pressure therapy and also for clinical management of pressure garments in the treatment of hypertrophic scar.

At the beginning of the 20th century, with the development of science and culture, the old solid support tight-fitting underwear changed to elastic fabric with darts (a tapering fold is sewn into clothing to make it fit) or lace up of tight-fitting underwear [131]. In 2011, with the general improvement of clothing comfort requirements and the popularisation of elastic fabric, pressure comfort had attracted the attention of many scholars, has become the focus on the field of comfort, about the impact of human physiological and psychological aspects [173, pp.250].

The pressure comfort as an essential factor in the daily function of underwear comfort, for this point of the research, was taken seriously until recently. M.N. Salleh *et al.* [161] has discussed a method to develop a pressure (clothing for medicine) distribution prediction model, the circumference and radius of curvature are calculated from the 3D wounded area data, and converted into a 3D pressure garment data to achieve the desired pressure. To 2016, A. Vuruskan and S.P. Ashdown [196] measured 9 bicycle clothing in 4 bodies with different size sstanding and cycling positions by AMI air pack sensor. Most tensions occurred at waistbands, most pressure locations on the bent leg increased slightly in the cycling position in comparison to the standing position.

In Japanese, as early as 1968, O. Shizue [140] measured pressure values of 12 positions on the human body in static and dynamic, while the pressure ranges at abdomen were 3.53...6.37 kPa (displacement deformation distance of -0.65...2.00 mm), waist was 3.18...4.81 kPa (displacement deformation distance -0.45...2.00 mm). In 1976, Horino *et al.* [73] simulative measurement by cylindrical., it was found that a decrease pressure may be related to the compressive deformation behaviour of the body; much allowance should be given to woven fabrics for comfortable feeling than to knitted fabrics. In 1982, T. Harada [65] explored the relationship between the skin stretch and the fabric elongation. A key variable affecting the pressure of the fabric on the body is the radius of the part being covered, the smaller the curve, the higher the exerted pressure, sections with smaller radii (for example ankles and wrists) require less fabric reduction to achieve the same garment-to-body interface pressure.

In 1993, H. Makabe *et al.* [131, pp.513-521] have studied subjective and objective measurement pressure comfort of a variety of bras and tight-fitting pants in dynamic and static, and found that three regions of the front waistline, thigh bottom and front thigh were prone to discomfort, the range was 4.00...5.33 kPa, and the average value on the waist was 2.46 kPa. S. Watanuki and A. Inamura [211, 83] tested the amount of heart output (in the left ventricle or right ventricle into the aorta or pulmonary arteries per minute) in three different postures of supine, sitting, and standing after wearing tight-fitting pants, and the large pressure the cardiac output showed a linear decrease trend, the heart output was significantly reduced while in the supine and sitting state. Moreover, the largest pressure provided in the groin by the bottom of tight-fitting pants based on these results. The bandages of shape and material at the crotch were redesigned, thereby the pressure on the human body and cardiac output are reduced.

In 1995, N. Ito *et al.* [84] studied the effect of the biaxial stretching of the fabric on the pressure comfort of tight-fitting pants. It was pointed out that the pressure on both sides of the body was larger than that of the front and back, the comfort values of the hip, sides and thighs were 0.8 kPa, 1.3 and 0.9 kPa, the compression ability of polyether-ester fabric more stable than the polyurethane (polyurethane). Y. Nagayama [136] made a comparison of taking off the tight pants and common pants separately, measured the data of recovering stage: the blood pressure, electrocardiogram, heart rate, and found the significant increasing pressure increased affects on heart rate, blood flow and some changes in the nervous system. In 1998, M. Nakahashi *et al*. [138] examined the influence of pressure imposed on the lower leg on the skin blood flow. They found the skin blood flow tended to decrease with increasing pressure. D. Tanaka *et al*. [181] investigated the effect of girdle pressure on the change in skin blood flow, and found that the skin blood flow increased when the material pressure was within the range of 1.99...3.33 kPa.

From 2005 to 2013, M. Nakahashi and H. Morooka *et al.* [137] conducted a study on the primary data of the comfort of the shaping clothing with different fabrics, structures and sizes, and analysed the subjective sensation (pressure, comfort, profile satisfaction) and physiological response (heart rate, skin blood flow and skin temperature). R. Yokoi [233] also studied the heart rate, blood flow, skin temperature of not wearing in supine position, wearing different sizes of pants in standing and supine positions. Through the test, with the clothing pressure increasing, the heart rate significantly accelerated, and leg blood slowed down, the skin temperature was lower when not wearing, but the supine heart rate is becoming larger, the skin temperature was higher.

From 2010 to 2013, the researchers of T. Tamura [180], pp.94-107], T. Kobayashi [102] and M. Sato [165] respectively did some pressure tested. Such as the pressure values measured on ten female lower limbs, with average values of 2.40 kPa (hips), 2.84 kPa (thigh) and 3.09 kPa (calf). Moreover, different kinds of clothing, average pressure value of tight-fitting pants (at lower limbs) was 1.08 kPa, the average value of tight-fitting T-shirt (at torsos and biceps)was less than 2.26 kPa, but for the average pressure value of males is higher, the value of bust (chest), waist ,and hips are 4.95 kPa, 4.99 kPa, and 4.98 kPa. In 2013, T. Toshiyuki [191] studied the pressure at 9 points of tight-fitting stockings, the comfortable average values were less than 4.50 kPa, the total calf was 3.70 kPa, the middle calf was 2.80 kPa, and the ankle was 2.10 kPa.

In China, this field of studiy started later. From 2005 to 2010, L. Mingxia [126] and W. Jinzi [203] measured on 96 static test points of 20 women’s bras, underwear and tight-fitting socks, the pressure range of underwear waistband was 1.73...5.93 kPa, the range of tight-fitting socks in the thigh and knee was 1.65...3.93 kPa, However, in the test more than 70% people receive a comfortable pressure at 2.20...3.00 kPa. Y. Shijia [236] measured 15 points of the whole body, the seamless underwear pressure average value was 0.98 kPa (material is 65% cotton and 35% Polyamide). J. Ziming *et al*. [90, 91, 267] measured 33 points of the male body and the value range was 0.32...1.46 kPa (80% cotton, 15% polyamide and 5% spandex).

From 2011 to the present, X. Meiling [223] found that the wear pressure distribution of the autumn and winter pantyhose is during 0.04...0.17 kPa. Y. Pei *et al.* [226] found the average pressure value of tight-fitting female pants was 0.4...2.5 kPa.

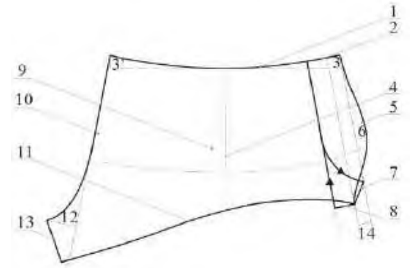
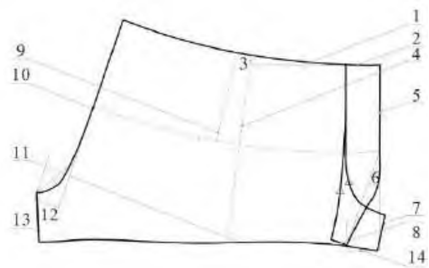
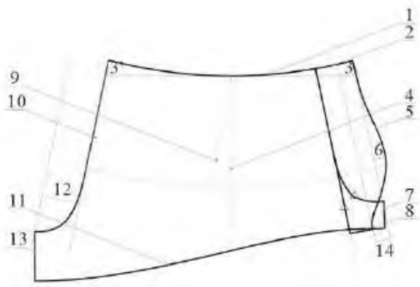
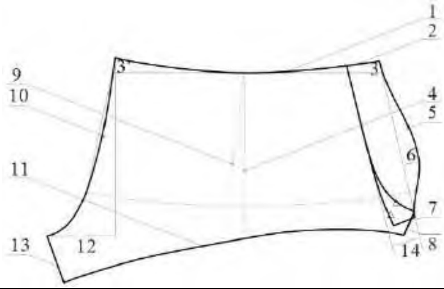
L. Yaping *et al.* [121] conducted a study on 9 points of 25 female abdomens and hips; the comfort range was 0.72...1.75 kPa, and the hip was lifting 0.59...0.65 cm under pressure during 0.90...1.27 kPa, abdomen tightened 0.92...1.06 cm under pressure value during 0.98...1.15 kPa. L. Lulu [124] did the same measurement study next year, the pressure values on abdomen and hip were 0.88...1.05 kPa and 0.89...1.07 kPa, while decreasing 0.72...0.85 cm at the abdomen and lifting 0.69...0.83 cm. L. Yao [120] got pressure range value of abdomen, hip, thigh and calf respectively were 0.96...1.55 kPa, 1.49...1.84 kPa, 1.23...1.66 kPa and 1.44...1.65 kPa, meanwhile the girths change of the abdomen and hip is 0.94...1.87 cm and 2.65...3.69 cm. Furthermore, G. Lei [57] and tested the 16 points pressure of male underwear after structural optimisation, and the average value was 3.89 kPa (mid-waist), 2.58 kPa (hip), 2.30 kPa (thigh). J. Erfan [87] studied male underwear comfort pressure, the waist was 2.20...3.70 kPa, below the hip was 2.00...3.40 kPa, the front crotch was 2.40...3.30 kPa, under the crotch was 2.40...2.80 kPa and leg was 2.60...3.40 kPa. Y. Wenxia [239] tested 26 kinds of fabrics pressure values with of 3 types of cylinders under different elongations, pressure value increases with the elongation increases, if under the same elongation conditions, pressure decreases as the radius of curvature of the cylinder increases. J. Zhennan [89] measured the 6 points of upper torsos on each three kinds women's tight-fitting yoga clothes (95% cotton and 5% spandex), and the range of average values were 0.29...1.49 kPa. Z. Lin [241] and L. Huashan [123] studied the pressure in the middle and late period of exercise; the medium pressure clothing can promote the alleviation of muscle fatigue, while the high and low-pressure clothing did not relieve muscle fatigue and even induced fatigue, the pressure of shoulders, upper arms, forearm are 2.57...3.41 kPa, 2.33...3.03 kPa and 2.19...2.89 kPa, and the pressure of thigh front, side, back are 0.50...0.78 kPa, 0.40...0.70 kPa, 0.40...0.65 kPa, hip is 0.78...1.29 kPa.

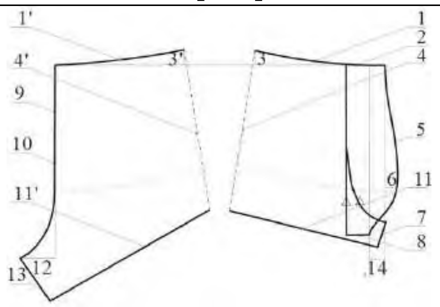
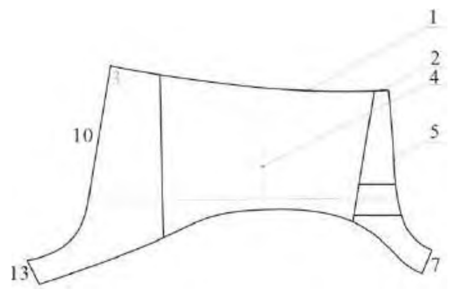
1.4. Modern methods of underwear design

Current existing men's underwear drafting methods in some teaching books, these patterns blocks were merely and only marked values of sizes, without explanations, mostly are empirical data and fixed values based on finished product measurements, and just the value of waistband girth is to rely on mathematical calculations. These cases are related to different factors of the system "body-clothes" – shape, materials, structure - and requirements for concerted in the pattern design. For example, Russian designers can use the limited number of pattern block making instructions including Muller and Son (Germany), Winifred Aldrich and Military method [216], but the possibilities of mentioned methods do not allow designing the contemporary underwear.

The method of Asian existing men's underwear is drawing. These patterns as shown in Table 1.1 with marked values mostly are empirical data and fixed values based on product measurements, only the value of waistband *No.1* is to rely on mathematical calculations. They are two-piece, and one-piece basic men's underwear finished size 170/88.

Table 1.1 – Boxers pattern blocks

	
a [230]	B [229]
	

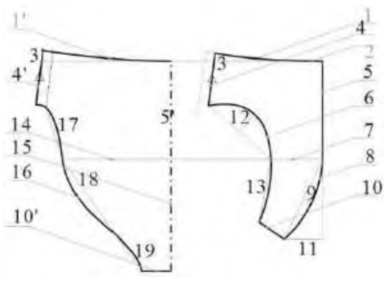
c [231]	d [16]
	
e [15]	f [271]

1 - waistband length, 2 - front insert top width, 3 - balance, 4 - side length, 5 - front insert middle length, 6 - front insert rise, 7 - inseam front part, 8 - pouch bottom width, 9 - waistband to hip, 10 - back centre length, 11 - bottom length, 12 - value of back crotch peak, 13 - inseam back, 14 - distance of front insert top and bottom.

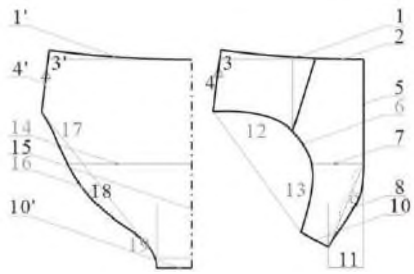
No.	*Size, cm*	*No.*	*Size, cm*
1	60 / 2+ 2...4.5	*8*	2.5...3
2	5	*9*	13...16
3	1.5...2	*10*	26...30
4	21...28.5	*11*	48
5	23...28	*12*	4...5
6	1.3...1.5	*13*	6.5...7.5
7	3.5...5	*14*	2...5

Table 1.2 shows the diagrams of drawings of men's briefs.

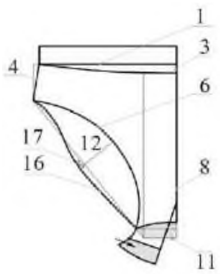
Table 1.2 – Briefs pattern blocks



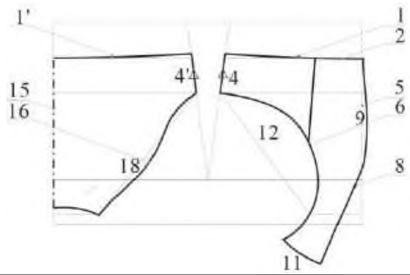
a



b



c



d

1 - waistband length, 2 –front insert width, 3 - balance, 4 - side length, 5 - waistband to hip line, 6 - front bottom length, 7 - front width at hip, 8 – front insert centre length, 9 - front insert rise, 10 - inseam front, 11 - front insert bottom width, 12 - value of upper bottom rise from line of sideseam and hip line, 13 - value of lower bottom rise from hip line and front insert bottom, 14 - back width at hip, 15 - back centre length, 16 - back bottom length, 17 - back upper bottom rise, 18 - back middle bottom rise

No.	*Size, cm*	*No.*	*Size, cm*
1	64 / 4 + 4.5	*11*	5...6
2	1 / 3 * waistband front	*12*	3.5...15
3	1.5	*13*	0.6
4	8...9	*14*	16.5
5	15	*15*	30...32
6	50	*16*	50
7	7.5...8	*17*	0.7

1.5. The effect of textile materials on comfort and design of underwear

In recent years, technical fabrics have been used to meet better consumer needs regarding the function of the base layer and particularly those technological advances that allow for better fit and comfort. Underwear is now made of spandex fibres, which offer excellent stretch capability, especially for garments with athletic capacity. From techno-fabrics to cotton blends with new weaves, the result is a second skin that is designed to stretch with movement and to fit snugly against the surface while remaining loose at the same time.

Comfort is being addressed in new ways to accommodate certain types of latex or rubber allergies [156]. For example, Hanes offers the "comfort soft" waistband design and has introduced a layer of cotton fabric placed between the waistband and the skin. In same tight-fitting kind of underwear, the fabrics with poor extensibility and considerable friction, the body will have a greater sense of compression; the other hand, it will be more comfortable. However, the resilience, flexibility and thickness of fabric also have a more significant impact on the comfort of underwear.

Fabric properties and clothing design are the two factors that contribute or impede clothing comfort. Fabrics have certain elasticity, woven fabrics are more rigid than knitted fabrics; knitted fabrics have excellent flexibility due to the interlaced structure. In general, elongation more than 15% are referred to as good stretch fabric and with elongation less than 15% is rigid fabric. Fabric with elongation more than 30% is called very good stretch fabric, and elongation during 15...30% is called "comfort" fabric elongation [49]. Close-fitting clothing made of such fabrics has minimum resistance to body movements, particularly around the elbows, knees, back and seat. The knitted fabric is more extensible than woven fabric, hence for tight-fitting clothing, e.g. underwear, the knitted fabric is preferred.

However, the research on the relationship between structural characteristics of a high stretch knitted fabric and clothing pressure are limited [163]. The high stretch knitted fabric is often used for the compression clothing because compression clothing should very fit (tightly) to apply pressure to the skin [108]. The pressure level (value) of a high stretch knitted fabric depends on the knit structure, yarn composition, and knitting type; however, little is known about the correlation of fabric size, stretch properties, and clothing pressure of high stretch knitted fabric [164].

Therefore, it is possible to develop compression products which can exert the exact required pressure on the body utilising the elasticity of knitted fabric [26]. However, an appropriate structure should be selected, arranged and used for specific body parts when designing compression products because different knit structures show different stretch properties even in the same fabric [162].

D. Lyle [127] indicated the better elongations of stretch fabric, comfort stretch is 25...30% and power (over the comfortable range) stretch is 30...50%. H. Lee [108] studied on compression therapy which utilizes medical compression garments and functional body shaping underwear design made of high power stretch fabric. M.L. Joseph *et al*. [93] identify that the amount of elongation for regular wear is between 10% and 25%, and for more active wear is between 35% and 50%. According to K.L. Hatch [66] the appropriate range of percent elongation for textile materials for tailored clothing is between 15...25%, for sportswear is between 20...35%, for active wear is between 35...50%, and for form-fitting garments is between 30...40%.

In 1993, J. Hu *et al*. [80] found a correlation between fabric stiffness and some objectively measured parameters with Kawabata, including coefficient of friction, the linearity of compression thickness curve, bending rigidity, and energy in compression fabric under five kPa. R.B. Ramgulam *et al*. [154] compared the method of measuring fabric surface roughness using a laser sensor with the conventional Kawabata contact method and found a relatively good correlation between the two ways.

2012, K. Taegyou [99] studied 13 kinds of tight upper sportswear, more than 70% of the upper body surface showed surface change rate are under 20%, fabrics elongations are 16.0...58.2% in warp, 23.1...78.4% in weft. In 2014, W. Yanting [219] tested and analysed three kinds of elastic fabrics (10...18 spandex, 82...90 nylon, %) properties with human body skin deformation in some sports actions. The fabric elongation of best matching extent at hip part was 88% in warp (144.4% in weft), front tight was 81% in warp (124.4% in weft), back tight was105% in warp (144.4% in weft),front knee wa 81% in warp (124.4% in weft), back knee was 81% in warp (144.4% in weft).

Fabric style is a comprehensive reflection of the fabric appearance, wearing comfort and beauty [132]. As early as the 30s, F.T. Peirce (British Cotton Textile Industry Research Association) [146] published “The handle of cloth as a measurable quantity” (1930), he firstly proposed the relationship between the mechanical properties of fabrics and hand feel, and make it expressed by data. J.W. Eischen [45] initiated research in the bending behaviour of fabric and the measurement of its material properties, he measured fabric flexural rigidity using a simple cantilever test and also modelled a typical woven fabric. By the 70s, S. Kawabata [95] began to study the mechanical properties of fabrics and published “The evaluation of the feel of thin men's suits and the emergence of the KES system” (1973). In the 80’s, N. Masako *et al*. [128] studied the relationship between primary mechanical properties of fabrics and appearance of the suit is investigated using discriminant analysis. A. Inamura [83] thought that the effect of the body shaping after wearing the tight-fitting pants was related to the softness of the tight-fitting pants material, the flexibility of the pants was related to the shear properties, and the stiffness was associated with the tensile properties.

In 2010, Y. Yua [227, pp.20-26] showed that the value of pressure was closely related to the shear properties, flexural properties and tensile elastic properties, the elastic modulus, transverse shear properties; the transverse bending behavior is positively correlated with the clothing pressure factor, and the flexible recovery performance of the fabric is negatively correlated with the clothing pressure factor. D. Xin [39, pp.12] tested eight kinds fabric of tight-fitting pants with five different sizes according to the standard pattern, the correlation among clothing pressure, tolerance, and elongation load were discussed, and the result of the elongation and load of the fabrics was got according to the comfort and beautify pressure. X. Hong *et al.* [220] studied that the change of warp or weft density led the change of the bending and shearing performance at the same time, while the warp and weft tensile properties have little influence on each other.

However, due to the high cost of KES equipment, complicated description of results, application background and other reasons, it has not been widely used by enterprises and research results at present.

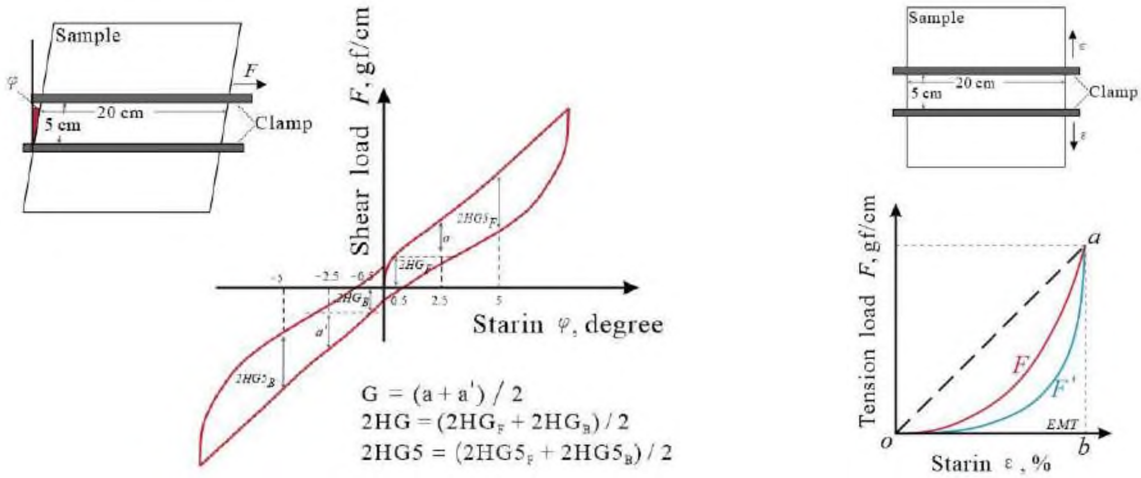
(1) KES-FB1 tester is used to measure the tensile and shear properties of fabric, non-woven, paper and film materials. It is used to determine the behaviour of a sample while under an axial stretching load [10]. The extension is defined as the change in length of a material due to stretching. The strain is the ratio of the extension of a material to the length of the material before stretching [31, pp.63].

Therefore, the tensile and shear change of the fabric, similar to the tension and deformation of the clothing worn on the human body, changes with body shapes, clothing structures and eases allowance design. Shear rigidity determines fabric stiffness or softness [86]. The shear deformation depends upon the friction and elastic forces within the fabric, so the values of shear properties are significantly affected by the fabric structure and finishing process (Figure 1.9 a and b). For example, the values of shear rigidity and shear hysteresis increase with the increase in weft density of woven fabrics [98].

(2) KES-FB3 tester is used to measure the compressibility and thickness. The compression test for fabric is used to determine the fabric thickness at selected loads

and reflects the fullness of a fabric [142]. The thickness of the fabric is one of its primary properties, giving information on its warmth, weight and stiffness [7].

(3) KES-FB4 tester is used to obtain frictional coefficients, fluctuations of frictional coefficients and surface roughness. Surface friction and roughness characteristic data are useful for determining fullness and softness, smoothness, crispness.



a b

Figure 1.9 – KES-FB1-4 diagram: a – tensile-strain, stretching and the area under tension curves (F), recovery (F'), and the triangle "*oab*"; b – shear-strain

Therefore, it is necessary to control the wear properties of the fabric [259]., in the final analysis, to manage the tensile shear properties, compression properties and surface properties of the fabric under low load. *E.g.* If the smaller the two values of fabric linearity of tension (*LT*) and shear stiffness (*G*), the fabric softer; when the greater of fabric stretch elastic recovery (*RT*), the stronger of fabric deformation resilience. Fabric comfort is also directly affecting consumers' purchase factors [245].

1.6. Computer-aided clothing design

With the improvement of science and technology in the apparel industry. The early drawing software such as Adobe Photoshop, CorelDraw, Adobe Illustrator, Corel Painter *etc*. In 80s, the CAD (Computer Aided Design) software: Auto CAD, Gerber Accumark, Lectra, Investronica Solutions, PAD System *etc*., these softwares in the clothing pattern block and other industrial design, making the integration of computer and industrial production techniques further enhance. Clothing CAD enables the industry to reduce product development cycles, reduce costs and increase profitability. Reducing design costs by 10...30%, reducing design cycles by 30...60%, and improving quality 2...5 times, equipment usage increased by 2...3 times, more quickly to adapt to the market demand, to put products in the market, also can get more and faster information. So, the popularity of clothing CAD has become an inevitable trend to enhance clothing industry competitiveness [166].

However, clothing CAD systems mostly focused on the 2D effects (design), which makes it difficult to predict the impact of the designed garment, and very difficult to achieve satisfactory results for the individualised consumer [42]. However, through the 3D system, it is easy to make human bodies and movement effects to 2D and 3D interactive design [32], to make customers see their dressing directly for the individual requirements, which played an excellent promotional and design role [43].

At present, 3D fashion design is still in the exploratory stage, there are still some more difficult problems, such as fabric texture and dynamic performance, realistic and flexible 3D reconstruction of surface modeling and so on. How to solve these issues is the key to the 3D practicality and commercialisation

1.6.1. 2D design

In 2005, China's clothing CAD penetration rate has reached 30% [212]. With the gradual maturity of all aspects of clothing CAD promotion, software technology has been a leap of development. However, the CAD application rate of the clothing industry is far less than Western developed countries [114]. The single function of Chinese clothing CAD system is still focuses on the fields of pattern block design, grading and layout, and has always been a passive position to rely on the advantages of low prices and localisation of functions to compete with multinational corporations. Currently Chinese and abroad for smart clothing CAD technology research is still in stage of exploration [119].

In the developed countries such as the United States and Japan, the popularity rate of clothing CAD systems is as high as 80%. “Gerber” in the United States, “Lectra” in France, “Investronica” in Spain, “Pad” in Canada, “Assyst” in Germany and “Toray” in Japan are all further developing towards to intelligent, integrated and networked direction.

Application of clothing CAD technology is not only a reflection of the size of clothing enterprises and the benefit but also the technical assurance to improve competitiveness. In the process of pattern block design, the structural design of a point, line and surface can accurately reflect the intention of the designer.

In recent years, CAD technology has made significant advancement, and the 2D clothing CAD technology has matured. The traditional 2D clothing CAD technology cannot provide the 3D representation of clothing and therefore can not meet the needs of clothing design. Accordingly, the development of 3D clothing CAD technology has become a universal concern in in the world [222].

There are several important issues in the event of 3D clothing CAD system, that is, the measurement and drawing technology of 3D human body, the technique of 2D graphics turning 3D, and the 3D virtual simulation technology [8]. Among them, how to quickly and efficiently build 3D body and clothing model is the basis of the research. Anthropometry is a crucial primary work in clothing design and production [262]. The human body is a complex curved surface; it is complicated to obtain more accurate, comprehensive human measurements data [11, 14].

1.6.2. Body measurement technology

Currently use the following methods.

1. Method of stereoscopy, using a set of cameras photography on the body at the same time, calculate the mannequin through the human body surface shape, cross-sections and curves scanned by lights [145]. However, this method is in line with human visual characteristics, so in some concave surfaces and dark parts are more difficult, also inaccuracy;

2. Method of laser body scanner, like German Vitus Smart XXL 3D, Human Solutions, Anthroscan software for visualization, processing and evaluation of data;

3. Moire topography is a contour mapping technique, which involves positioning a grating close to an object and observing its shadow on the object through the grating [252];

4. Method of white light, using white light to project a sinusoid on the surface of the body, raster deformed by an irregular shape and resulting image will represent the body shape [251], such as the TC^2, Telmat.

1.6.3. 3D virtual technology

3D design system allows the importation of 2D pattern blocks from the appropriate CAD software, then to wrap them onto a virtual model to visualise the virtual clothing and to simulate fabric drape and fit. This CAD group includes Vidya (Assyst-Bullmer), CLO 3D 5.1, Marvelous Designer (CLO Virtual Fashion), Vstitcher (Browzwear), Accumark Vstistcher (Gerber), Haute Couture 3D (PAD system), Modaris 3D Fit (Lectra), E-Fit Simulator (Tukatech), and 3D Runway (Optitex) *etc*.

The Vidya enables the creation of customized virtual mannequins based on the customer’s market and specific size tables and body-scanned data. It can visualise 3D clothing design (Vidya) from 2D patterns (Assyst Cad software) [4] and simulate fabric drape on a virtual mannequin. It can affect seams, buttons, seam lines, linings and folds in the 3D design, it allows the designer to add colors and textures as per the preference. It comes with a range of fabrics in its standard library which can be expanded by inputting any fabric characteristics taken from objective fabric measurement systems such as KES and FAST.

The first applications for mechanical cloth simulation appeared in 1987 with the work of D. Terzopoulos *et al*. [184, 185] in the form of a simulation system relying on the Lagrange equations of motion and elastic surface energy. S. Krzywinski and B.K. Hinds *et al*. [100, 70, 71] studied the tight clothing on the 2D transition to 3D system issues which refers to the relationship between the force pressure and fabric elongation.

During 2000 to 2006, T. Vassilev *et al*. [194] developed a technique for virtual clothing body, and this method can fast simulate dressing people. H. Rödel and T. Igarashi *et al*. [157, 82] evaluated the physical properties of different kinds of fabrics and the pressure comfort after virtual dressing by using 3D technology and Kawabata instrument, which provides a reference for fabric performance selection.

In 2002, F. Cordier *et al*. [30] studied on the gap (space) between the clothing and mannequin and divided this gap into three types according to the amount of the clothing model; various methods calculate different types.

In 2013, T. N. Magnenat *et al.* [130] presented the online virtual try-on application that assists users in the evaluation of clothing in online shopping; the users can create a virtual size of themselves, and make them try-on clothing and move.

In China, from 2003, C. Wang *et al*. [197, 198] presented a clothing design system that allows users to design 3D clothing around mannequin through the 2D pattern block drawing. To 2004, K. Fujun and H.B. Wang *et al.* [55, 109, 133, 202] developed software to achieve human modelling and 3D simulation of the dressing, it is possible to observe the effects of various clothing styles in multi-angle, and lay a solid foundation of virtual try-on by drape simulation and collision detection for fabric, clothing dynamic deformation. M. Suhua [134] analysed and summarised the characteristics and advantages of virtual fashion design. As a case study of a dress, we realised virtual fashion design by using CLO 3D software.

In recent years, 3D clothing virtual technology (P. Volino 2000; E. Turquin 2007; O. Sabina 2015 etc.) [193, 195, 160], and 3D fitting room technology (D. Protopsaltou 2002; W. Zi 2006; W. Xiao 2014 etc.) [149, 197, 202], are hot issues in academia and business and research.

As a new concept, virtual production is called the main mode of manufacturing in the 21st century. This is an important symbol of digital design and production technology [232]. In production, the cost of the design phase is 5% of the total cost, but it determines 70% of the product price. This requires manufacturers to rethink the importance of work at the design stage. Virtual design is one of the most important technologies in the digital age. This is a new method based on computer-aided design and developed using the technology of "virtual reality" is especially attractive for linen, because its modeling eliminates the need to attract physical objects (real figures and clothes).

The purpose and directions of the dissertation research

1. Based on the analysis of published research results, it was established that the initial knowledge base for designing men's underwear is insufficient. There are practically no comprehensive studies in which the final design object – underwear with a set of certain functions – would be considered from several points of view, namely, the morphological features of the lower part of the body and their corrections by applying allowable mechanical loads, compressive performance of knitted materials, and rational division of underwear. Currently, theoretical studies of men's underwear are rare.

2. Analysis of the known design techniques showed that the number of dimensional features used in them is extremely small to describe the morphological

features of male bodies, and the dependencies used are derived from the experience of developers and are not statistically supported. The existing methods are designed to obtain textile shells to cover the lower parts of the bodies and do not contain recommendations for its adjustment. Therefore, it is necessary to develop a new technique, which, as a goal-setting function, would involve changing the shape plasticity and providing comfort.

3. The existing books in the method of pattern block making are mostly accumulated through experience. Moreover, Chinese institutions have not yet set up some course about underwear or tight-fitting clothes structural design. The primary theoretical research is weak, the underwear industry design through the ways of self-exploration and experience is contrary to the underwear industry to develop the situation in a recent year.

4. The existing classification of male bodies is total and applies to the whole body. With this approach, it is difficult to identify those characteristics that have helped manufacturers of underwear to choose the target groups of consumers. The transfer of the classification of the total size of the bodies on the marking of underwear is clearly unwise and illogical. Therefore, the development of a new universal classification of male bodies is an important scientific problem for the creation of science-based principles for designing underwear.

5. Modeling and verification of underwear is faced with ethical problems, for this reason very little scientific data. Modern virtual technologies allow the simulation of many processes, including the adjustment of bodies, the deformation of soft tissues, unprecedented selection of underwear. Therefore, the development of technology development of digital counterparts bodies and underwear is the current direction.

In the market, the status of men’s underwear are gradually strong, and the problems and disadvantages are revealed. The study of men’s underwear, unlike other clothing, has a mature scientific achievement, but also mainly in the empirical design, without a reasonable scientific experiment. So, most of the products will not be unwell for wearing comfort. Which led to development resistance about the classification of men’s underwear type in the current market.

Chapter 2. ARTISTIC AND CONSTRUCTIVE DATABASE AND CONSUMER PREFERENCES OF MEN'S UNDERWEAR

2.1. Artistic and constructive database for men's underwear design

At the beginning of our study, we have collected more than 1000 items of men's underwear images and products. Such as 2xist, Jockey, C-IN2, Andrew Christian, diëtz, Unico, Calvin Klein, Hugo Boss, Emporio Armani, Miiow, JianJiang, I'd, Septwolves, NanJiren, *etc*. In the collections, some manufacturers have introduced the "push-up" effect (or other correct functions) to their product. There are about 1/3 based on the characteristics of underwear fabric to make "push-up" effect on the male body; another 2/3 underwear proved this effect based on the new style and the new structure design.

The market demands, the constant expansion of the assortment and the increased demands of consumers for comfort, which must be reacted formed by the following trends that have appeared recently.

1) Changes in the design of men's trousers. Significantly changed the parameters of the properties of materials, which became much lighter and more plastic due to the appearance of stretch materials. Reducing the volume of modern men's trousers, increasing the degree of their anthropomorphic also became a factor that influenced the new methods search of compulsory shaping of the lower part of the torso with the help of underwear.

2) Changes in the requirements for artistic design. The first of the designers who turned their attention to the aesthetic function of the linen was Calvin Klein, who printed his logo on the belt. This decision affected the position of the trouser belt, which fell below the waistline and made the underwear belt visible (Alexander McQueen became the author of such trousers). Special popularity is gained by special decoration techniques among the consumers of different groups (children, boys, men):

the use of materials with thematic drawings, decorative inserts that emphasize the different parts of the body.

3) The strong influence of sportswear, which is expressed in the use of internal curvilinear dynamic lines and methods of their accentuation. The fascination with fitness, the cult of a healthy body also influenced the change in the structure of underwear, such as the more dynamic shaping of the contours and lines of division.

4) Change of underwear functions include not only the maintenance of external genitals but also the special space that they must occupy, in combination with increased comfort. The push-up effect (previously translated - forward and upward), previously appeared in women's corsets, brassieres, tight jeans, became popular in men's underwear to visually increase the volume of the lower torso in front and back. From the front, the push-up effect is achieved through the special design of the front part (the so-called anatomical cut), which provides a natural lifting. The design of the front part can be designed in two versions: with a molded inner soft insert in the form of a bowl (similar to female bras) or without it.

5) The emergence of new innovative knitted materials, as well as the technology of obtaining seamless products increased comfort and the ability to adjust the shape of the figure at low loads. The stretchability of such materials reaches 20 ... 80% with an average extensibility of 25%. In some models of laundry, several types of materials are combined in differentiated areas.

2.2. Underwear structure design

Daily underwear. That is the basic style and structure, it is divided into – front insert piece (front pouch, left or right pieces together or one piece, in common, has double layers). Front piece (in front thigh part, on both side of front insert piece); a back piece (with centre seamline or not); has side seam on both sides. This kind of underwear has simple structural features, relatively free size (commonly the general size of the average type of the body), and has a large output.

However, this underwear price is low and is easy to buy in the market with many styles, which is suitable for low-end consumers, so it does not require comfort and other functions, only focus on its material. As shown in Figure 2.1, we have listed the daily basic structural boxers and briefs.

(2) Compression tight-fitting (correction effect) underwear. Its front insert part uses the structure type of basic underwear, only design in the width of the front insert part. However, the side or back part design the structure lines to enhance the visual effect and increase the variety of fabrics and colour, thus the beauty and the fitness has been enhanced.

As shown in Figure 2.2a, b, c they are contemporary fashion types of tight-fitting underwear. The “egg” pouch of front insert can make male genitals lifted and separated from the thighs, with the correct, aesthetics, sport and health functional. Figure 2.2c, d, e show that the unique design is used to correct the tight parts of the underwear, and to reduce the bottom deformation.

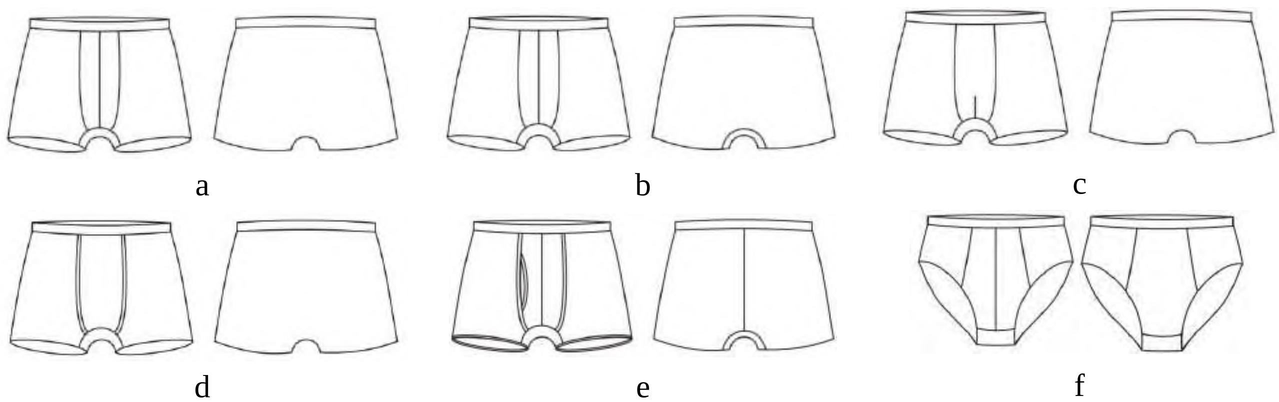


Figure 2.1 – Typical daily underwear: a – Front insert piece, an inseam jointed by front and back pieces. Disadvantage: single style, unfit, the seams at crotch part (inseam, then sew seams of crotch and lower hip, front insert seams) easy to break, bottoms of thigh easy deformation; b – Basic type based on a, has a separate crotch piece; c– front insert without complete centre seamline only has a single-pointed dart (concave dart) below; d – Front insert without centre seam, the structural stability, bottoms are not easy to deformation; e – front has opening at the side, one crotch piece and back middle seamline; f – the front part is composed of left and right pieces, without separate crotch piece; front insert without center seamline.

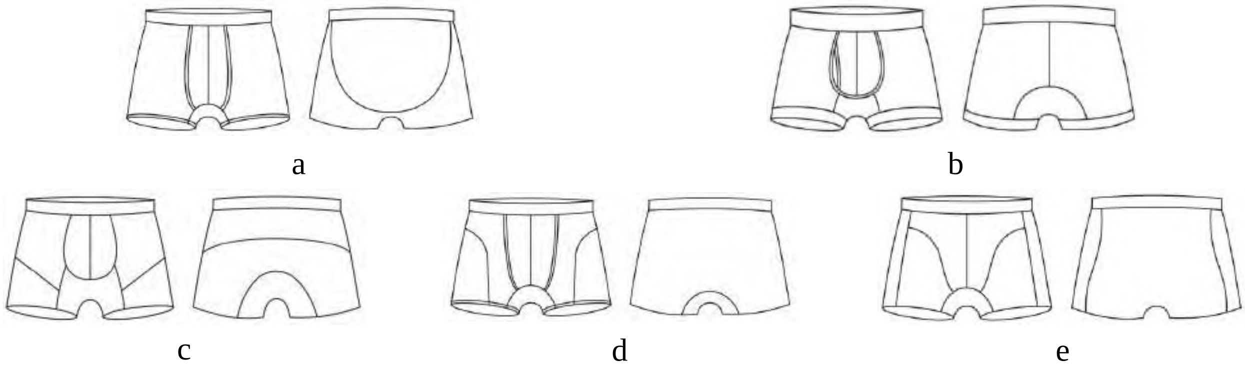


Figure 2.2 – Compression pressure and correction effects underwear: a – Structure line through the side to hip and crotch, this seam closely to hips and lower hips, with the function of lifting; b – Opening at front insert side, a separate crotch curve seam sewing with the back piece below hip level, back with a centre seam. Thigh bottom with elastic tape, to make bottom closely to thigh; c – Divide back part into upper and lower pieces, a seamline around the hip level to front thigh middle joint with separate crotch piece front; d – Curve line divides the front thigh piece from sideseam part into both sides. Front narrow pieces prove a good fit; e – “T” type front insert and separate sidepiece on both sides.

In China, the most inseams are located in the inside middle of two thighs, below the crotch. However, in general, in crotch part is usually designed a separate crotch piece, and the seamlines/edges of the crotch piece are in back lower hip and front thigh. Underwear is divided into 4 parts: crotch piece, front insert (pouch) piece, front thigh and back hip pieces. This design of a separate crotch piece is the same as the women’s underwear crotch; the purpose is to fit the body, reduce the unnecessary structural lines in a dense area.

Figure 2.3 shows the location of the common structure lines in the functional underwear abroad. It can be divided into – front insert, including the left and right part, and the value of the variable represent its width, length and height; the inner seam can be located anywhere of thigh inner surface. After style analysis, it provides an ergonomic optimal matching position preferably on the anterior surface of the thigh. Underwear back piece can be divided into three groups of structural lines: a group crossed the lower part of the belt and linked to the front groin area that connected the front and rear; the second group with U-shaped structure line designs is around the waist and hip; the third group with the arch crotch low design hold up the buttocks.

The front (Figure 2.3a) insert consist of two symmetrical parts, has a nearly constant position at the bottom, and variable quantities are its width, the radii and the configuration. The bottom of insert location defines the maximum possible “push-up”. Inseam can be located anywhere along the inner of thighs, but mostly on the anterior (Figure 2.3b), which provides better ergonomic compliance in the characteristics of physical activity. The most variable structure lines design is on the back (Figure 2.3c). They can be divided into two groups, the first group is inserted into the lower buttocks at back part to achieve the “push-up” effect, and the second group is across hips to divide back part into upper and lower parts, and then extend to the side of front insert to make high hip closely and lower hip up. The position of the bottom (Figure 2.3d) depends on its type and can reach the first third of the thigh [273].

a

b

c

d

Figure 2.3 – Variants of constructive solutions and location of the lines of internal division: a – front, b – inseam, c – back, d – position of the bottom

2.3. Customer preferences investigation

Nowadays, very few works deal with the analysis of men’s underwear feeling feedback. For all these reasons, it has appeared as relevant to carry out an inquiry dedicated to male consumption habits, needs and expectations regarding their underwear at national and international levels [97]. However, few studies about the purchases behaviour of male consumers are published, and very few works of them deal with the analysis of their feeling feedback [248].

The content of the questionnaire has been designed based on the evaluation of functional requirements and the evaluation of comfort. In the process of this investigation, several ways like a literature survey, interviews, network questionnaire, and the physical questionnaire are utilized. Based on previous literature and market researchers, this study is about necessary consumer information (age, size, own types and quantities, prefer brands), purchase habits (purchase frequency, main preferences – type, material, color, function, and others) and wearing expectation (main focus, wearing frequency, wearing comfort, and others).

The questionnaire investigates the male population in four countries, mainly youth-oriented (college student) from Russia, China, France and Bangladesh. 783 males from 18 to 57 years old have been surveyed from 2016 to 2017. The investigated panel was composed of 674 Chinese, 74 French, 30 Russians, and 5 Bangladeshis. The initial questionnaire has been improved thanks to a pre-survey. Therefore some professional information has been added to the final survey. In this study is planned and conducted to determine whether or not the difference exists in the purchase and wearing preferences of male behaviours in four countries. It has been concluded that the differences are significant among the respondents in 4 countries [274]. 204 questionnaires were surveyed by rank evaluation of 5 levels among the 674 Chinese respondents, such as: “1 (Very dislike), 2 (Dislike), 3 (General), 4 (Like), 5 (Very like).

We have selected 12 variables, psychological (preferences) variables, behavioural (purchase) variables and physiological (feelings) variables as the main three categories, as follows:

- Psychological (preferences) variables – preferences of underwear type (X_1), preferences of functional (structural line) design (X_2), preferences of style (waist height) design (X_3), preferences of the tightness (X_4);
- Behavioural (purchase) variables – purchase underwear type (X_5), purchase

size (X_6), purchase focus (X_7), purchase frequency (X_8), purchase brand (X_9) ;

- Physiological (feeling) variables – feeling (uncomfortable) of wearing (X_{10}), dressing (way) habit (X_{11}), dressing (functional) demand (X_{12}).

The information above manifest that the KMO (Kaiser-Meyer-Olkin) statistic is 0.89 > 0.7 (Appendix I, Table I.1) and the factor analysis is very active. Bartlett's test shows that the applicability of factor analysis can be obtained (*sig. = 0.00*).

Through the "total variance explained" analyzed by SPSS, the eigenvalues, the variance rate and the cumulative contribution rate are obtained according to the calculation of the correlation coefficient matrix. From the variance contribution rate (Appendix I, Table I.1), the first seven factors can reach 83.24%, the rate of variance of the first three components are 42.29, 10.99 and 8.47%. Therefore we choose these seven factors to describe the consumption pattern of male consumers well. We use the method of principal component factors to calculate the variables of the seven factors' load and carried out the maximum variance orthogonal rotation. It can be seen from the factor loading matrix (Appendix I, Table I.2),

- First component factors have a more significant load on the variables of X_5, X_1 and X_4, which we will name the "underwear type/style factor";
- Second component factors have a larger load on the variables of X_{12} and X_2, we named them "underwear function factor"; Third "purchase(frequency and brand) factor" are variables X_8 and X_9; Fourth "underwear wearing (waist position) factor" are variables of X_{11} and X_3; Fifth "underwear size factor" is variable of X_6; Sixth "underwear focused factor" is variable of X_7; Seventh "underwear (uncomfortable) feeling factor" is the variable of X_{10}.

Thus, we can know that the consumer's consumption patterns are composed of 7 mainly factors. as the order is underwear type/style preferences (and purchase), functional demand (and preferences), purchase (frequency and brand), wearing (waist position), size, focus point, (uncomfortable) feeling. Then, we follow this sequence to the next discussion by order of their psychological, physiological and purchase behavioural preferences.

2.3.1. General results of consumer survey

In totally, the range of the underwear size can be seen in Figure 2.4 and 2.5. As it could be observed, most underwear sizes are concentrated in the L, XL and M,and the more popular underwear sizes are L and XL.

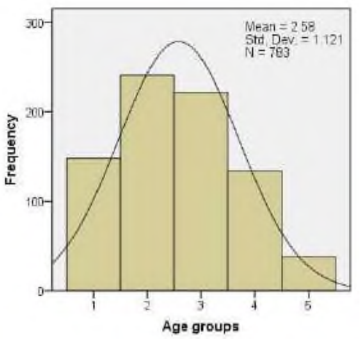


Figure 2.4 – Histogram of age distribution, * 1 – Teenager, 2 – 20...25, 3 – 26...35, 4 – 36...55, 5 – >55

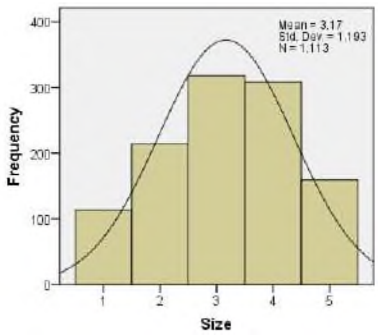


Figure 2.5 – Distribution of underwear sizes, * 1 – S, 2 – M, 3 – L, 4 –XL, 5 – XXL, there have six respondents unclear

1. Psychological preferences. About the variables of preferences (X_1...X_4), the first component factors are underwear type (X_1) and tightness (X_4), and the functional (structural line) design (X_2) is a second component factor, a factor of style (waist height) design (X_3) is a fourth component factor.

Preferences of underwear type. According to the first component factor of underwear type/style preferences (and purchase) factors. The more popular type in four countries is the boxer-briefs (26%), followed by – boxer-shorts (17%), boxers (16%), briefs (15%), thongs (9%), jockstraps (5%) and bikinis (3%). It can be noticed that 3% of males do not wear any underwear (3%).

Preferences of underwear tightness. Concerning the first component factor of own products and tightness of the underwear during different age groups, the survey results show the following ranking (Appendix I, Table I.3): the higher score belongs to the tight-fitting underwear and then to very tight-fitting, regular, and loose-fitting.

To analyze the findings of the respondents' age range, the age range has been divided into four intervals, the preferences of tightness for selected groups are average:

- Aged less than 25 and 25 to 35 prefer the tight-fitting boxer-briefs similarly;
- Aged 35 to 55 prefer the regular boxer-shorts;
- Aged more than 55 prefers the loose-fitting briefs mostly.

Due to change in body shape under ageing, the behaviour and preferences of underwear functional features and type selection also changed. The elders pay attention to comfort, convenience and durable (Güzel, 2013) [61]. The preferable type for the elders is loose-fitting or regular briefs.

Preferences of underwear functional (structural line) design. As for the second component factor of underwear functional preference. For the structural design of current underwear, the respondents prefer the push-up feeling in the back (hips) and the front (genitals) respectively 52.2% and 54.1%. "Push-up" is the correction effect on soft tissues. Thirdly, there are no clear structure line preferences which can be noticed that more than 36% of the respondents prefer the classical "few seam" structure, 24.7% of the respondents do not know which design is better, and the limited numbers of respondents like underwear with many structural seams (13.3%). We can identify the respondents who are defining their preferences between the seamless underwear and the underwear with few seams (25.7%). Seamless underwear belongs to most consumption in Europe (Chen *et al.*, 2016) [116].

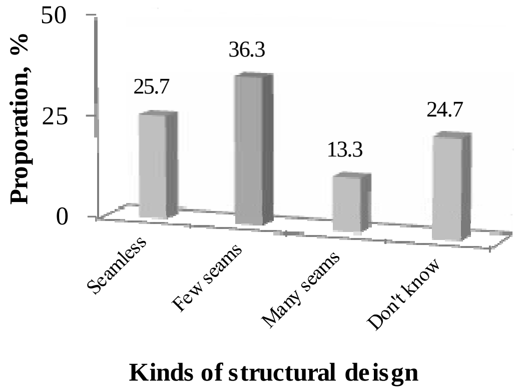


Figure 2.6 – The distribution of structural design preferences

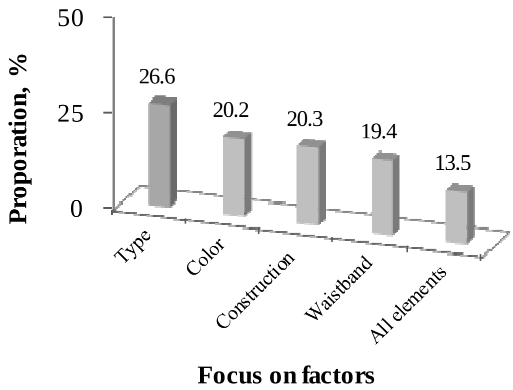


Figure 2.7 – The distribution of focus factors

Preferences of underwear waistband position. The waistband position is the fourth factor, but most of the respondents (53.4%) prefer the waistband below 5...7 cm than the natural waist as the more famous underwear style, then, prefer the waistband below 8...12 cm; and the position below 4 cm (only 17.1%), is mainly for the primary type of underwear, mostly for the senior men with the simple structure of underwear. Moreover, just 4.8% of people accept the waistband lower 13 cm such as tongs and jockstraps.

2. Purchase behaviour. As for all variables (X_5...X_9) of purchase behaviour, the first component factor is purchase underwear type (X_5), and the third is frequency (X_8) and brand (X_9), the fifth and sixth are purchase size (X_6), focus point (X_7).

Purchase underwear type. Concerning the number of pieces people purchased themselves), the rank are the boxer-briefs (22%), briefs (21%), boxers (19%), boxer-shorts (13%), swimwear (10%), thong (6%), jockstrap (5%) and bikinis (4%). Regarding some pieces, most of the panel member own from 8 to 12 pieces; the smaller number own four pieces.

The situation in purchasing and brand preferences. Overall, 56.3% of the respondents had some questions before and after purchasing underwear, but more than 85% of the respondents have no questions/problems before purchase and more than 75% who do not ask for help. Most respondents bought new underwear in half a year (29%) or irregular (38%). There is no relatively fixed purchase cycle or purchase plan, usually, encounter the right will lead to purchase behaviour, and the higher purchase frequency (monthly purchase) of consumers are in the minority.

30.6% of respondents did not identify their underwear size, 25.6% of respondents did not identify the out looking after wearing underwear, and 24.7% of respondents did not identify which underwear design is more suitable for them. Other reasons affected the purchase behaviour of 19.1% of the respondents are the price, brand, function and others.

In daily life, people did not consciously change their personal preferences and wearing ways. As for the individual underwear collection, more than 70 % of the respondents have changed their behaviours due to preferences of the purchase. Most people changed own taste (36.6 %) which affect the purchase behaviour of underwear style/type, the following reason is their own physical changes reasons, for example, body shape became better (22.5%), or became worse (14.9%), income changed (25.9%).

Figure 2.8 shows the distribution of brands (the majority of Chinese brands we separated display on the right) which the respondents usually choose to buy. The international brands such as Zara, C&A, Uniqlo, and the others have large amounts of global shops with a high acceptance price for mass style productions. So, its acceptance is near to the more well-known international brands like Calvin Klein and Hugo Boss. As for Chinese brands, the differences between each respondents' preference are influenced by high acceptable brands, new style, update speed rapidity, structural design, and the characteristics of fabrics. About the commonality of low accepted brands, in addition to price factors, the simple structure, single material without good features (Zhang *et al.*, 2011) [69].

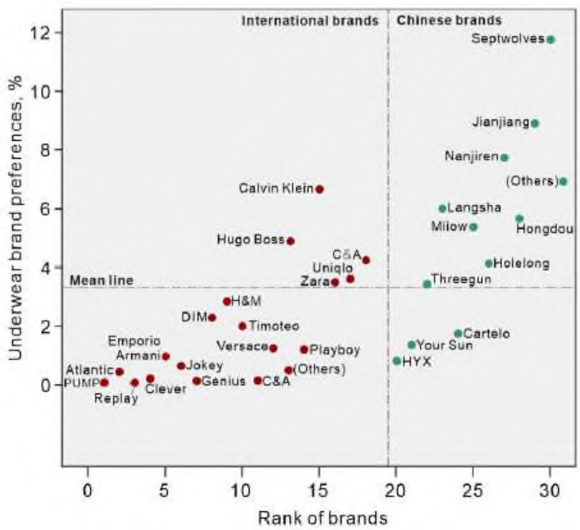


Figure 2.8 – Distribution of underwear brands preferences

Underwear size. The range of the underwear size can be seen in Table 2.1. It is noticed that the six respondents ignore the size of their underwear. It means that they are not the buyers, the question still open. As could be observed, most of the underwear sizes are concentrated in the M, L, XL range. The more popular underwear sizes are L and XL; and we can find that with age growing, the fit/prefer size becoming larger; males less than 35 fits/prefer smaller sizes M and L; more than 55, s need larger size XXL.

Table 2.1- Distribution of age groups and fit sizes

Age groups	Age distribution, %	Distribution of underwear sizes, %					
		S	M	L	XL	XXL	Unclear
<25	41.6	12.1	25.0	23.8	22.1	15.0	2.1
25...35	28.3	11.1	23.1	24.9	22.2	15.1	3.6
35...55	24.2	14.3	19.9	22.4	24.5	17.1	1.9
>55	5.9	11.8	17.7	23.5	17.7	23.5	5.9

Personal focus factor. The type, color, and structural design are the most critical indicators to buy underwear. For the type, we have mentioned above. For the colors, the respondents prefer black (15.0%), grey (13.3%), and dark blue (12.6%); the other colors (12.0%) preference is less than 10%. Because the respondents in the four countries had a major impact on different emotional categories, there was a significant difference in the color preference for underwear. For the material, the half of respondents prefer raw cotton (30.2%) and cotton with synthetic fibers (19.8%). Now, the men’s underwear material with Lycra (prefer rate is 18.8%) is the most common underwear material in the Asian market, 2 to 8% of Lycra is added to cotton fiber or regenerated cellulose fiber, and it does not change the appearance of the material, but can significantly improve its performance.

3. Physiological (feeling of wearing) of underwear. As for the variables of physiological feeling (X_{10}...X_{12}), underwear wearing (functional) demand (X_{12}) and wearing (way) habit (X_{11}) are the second and fourth factors, and the (uncomfortable) feeling of wearing (X_{10}) is a seventh component factor.

Underwear functionality demand. The survey of a second component factor. It was apparent that the people have a higher requirement (34.2%) for comfort. Secondly, the preferences related to the functional design in front (genitals) were suitable for the one fifth, followed by the functional design in both parts (14.7%).

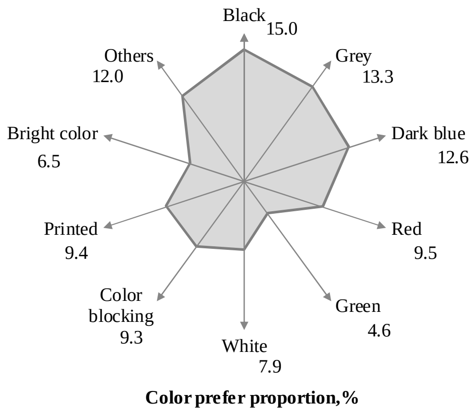


Figure 2.9 – Distribution of color preferences

Underwear wearing way. The fourth component factor. When the respondents choose the underwear for daily, they should consider the type of pants (trousers), for example, tight-fitting underwear with slim jeans or loose-fitting underwear with baggy pants, 44.4% of the respondents think about the future combination whenever they try to adapt the shapes of pants and underwear. The one-third of respondents never consider the styles of the underwear and the pants; they do not change the underwear style when replacing different pants. The quarter of respondents do not necessarily consider the combination of both styles – underwear, and pants, but they care about this visual effect or comfort feelings.

As for the habit of wearing underwear with pants, only one-third of respondents prefer to expose the waistband of underwear. Most of the respondents (68.0%) prefer to make underwear waistband below the belt of pants.

According to the underwear wearing time, more than half of respondents wear the underwear all day (55.6%) or during the day-time (24.2%), only a small part of respondents (8.8%) preferring to sleep in nude.

Positions of uncomfortable feelings. From the investigation of the seventh component factor of underwear discomfort. The main influencing factors come from a lack of structural design, which leads to structural defects of the critical parts and the actual feeling of wearing decline. So, it is necessary to optimize this part. The half of respondents felt that the discomfort feeling comes from the front (28.5%) and the crotch (21.8%) area. 17.3% and 10.3% of respondents felt that it caused by material and waistband, and 22.1% of the respondents explained that the discomfort conditions are arising after the next feeling. Underwear size does not meet their own size (too tight or loose), unreasonable structure design, and so on.

At the level of probability 99.9% (0.001), significant at the 0.01 level (two-tailed), n > 700, we can see the correlation coefficient between underwear tightness and discomfort parts/reason in Table 2.2 by SPSS.

Table 2.2 – Bivariate analysis (Pearson's correlation *r*)

		Very tight-fitting	Tight-fitting	General	Loose-fitting	Very Loose-fitting
From material	*r*	**0.28**	0.05	**0.27**	0.11	0.06
	sig.	0.00	0.51	0.00	0.13	0.02
In front area	*r*	0.02	**0.18**	**0.23**	0.11	0.03
	sig.	0.79	0.01	0.00	0.12	0.66
In crotch area	*r*	0.11	0.01	**0.21**	0.09	0.12
	sig.	0.11	0.92	0.00	**0.23**	0.09
In waistband	*r*	**0.25**	0.11	**0.16**	0.04	**0.21**
	sig.	0.00	0.12	0.02	0.57	0.01

According to the respondents' feedback, the underwear structure design is not according to ergonomics, and the lack of material performance will bring discomfort in the crotch and the front. We can find that most uncomfortable feeling caused from the general fit type of underwear with higher correlation coefficients and significant at 0.001 level; but for very tight-fitting and very loose-fitting types of underwear, the uncomfortable feeling exists in the waistband. For the uncomfortable feeling of tightly supporting in the front area, we find that respondents can have good acceptability of underwear tightness from low to high – general to very tight-fitting, and they feel not good (not closely, wrinkle, structural design defect *etc*.) in the crotch area of the general type.

2.3.2. Result of f national preferences

The investigated group was composed of 674 Chinese, 74 French, 30 Russians, and 5 Bangladeshis. , 204 questionnaires of 674 Chinese respondents were surveyed by rank evaluation of 5 levels, such as 1 (Very dislike), 2 (Dislike), 3 (General), 4 (Like), 5 (Very like). All Chinese questionnaire items were analyzed “reliability statistics” by SPSS, valid cases n = 204, Cronbach’s Alpha is 0.94.

1. Psychological preferences. Preferences of underwear type. The quarter of the Chinese, 70% of the Russians and half of the Bangladeshi respondents prefer boxer-briefs; but nearly eighty percent of the French respondents prefer boxers (with some structural line design).

Thus, we took two types of boxer-briefs and boxer-shorts to “crosstabs statistic” with different age groups by SPSS (Appendix I, Table I.4 and I.5). We can see in total, a half percent of each age group like boxer-briefs, forty percent of respondents like boxer-shorts and one-third hold the general attitude. The proportion during ages 20...55 are more steady, except preferring boxer-shorts at ages 36...55, then preference to boxer-briefs on the upward trend as they grow older. Some teenagers dislike boxer-shorts, but most respondents of more than 55 prefer this type. Most respondents from 4 countries have briefs, boxer-briefs and boxers, most Russians and French respondents also prefer boxer-briefs and boxers. So, even the briefs have higher ownership and lower preferences in four countries; we can assume that the type of briefs is not accessible nowadays.

Preferences of underwear tightness. The most respondents prefer the tight-fitting underwear in regular style. The one-third of the Chinese respondents prefer the very tight-fitting style, and the proportion below 35 years old is 80%. More than one-third Chinese, Russian and Bangladeshi respondents prefer underwear with few structural seams. However, near 70% of the French and more than one-third of the Russian respondents do not know which kinds of structural design they are preferred (Appendix I, Table I.6).

Seamless underwear market is not significant in China enough, just became popular in recent years in Chinese coastal cities due to the high prices. The Chinese consumers may have a particular interest and try to buy and to wear.

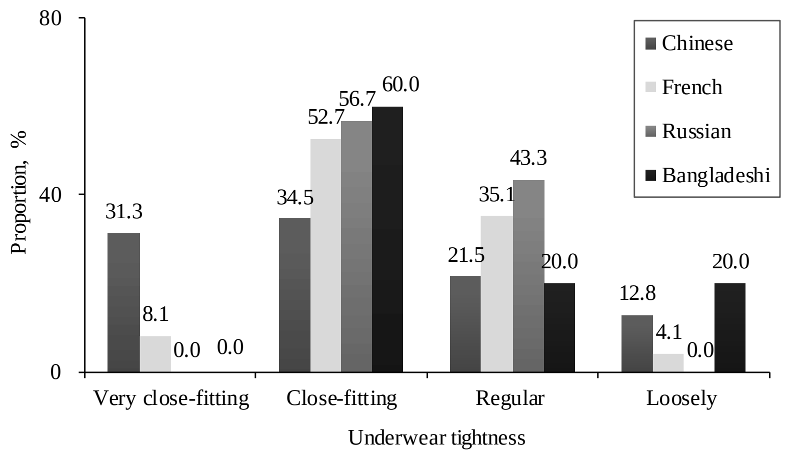


Figure 2.10 – Distribution of underwear brands preferences

Preferences of underwear functional (structural line) design. The respondents' acceptability of push-up feeling that is generated by existing underwear in front and back parts. As we can see, only more than 60% Chinese have the highest acceptability (or suitable experience). Nevertheless, other respondents only have lower acceptability (average less than 25%) to the push-up effects in front and back.

Preferences of underwear waistband position. The most of Chinese (51.3%), French (63.5%), Russian (60.0%) and Bangladeshi (51.3%) respondents prefer underwear waistband below 5...7 cm.

2. Purchase behaviour. Purchase underwear type. The Chinese (62%) and the Russian respondents (83%) have 5 to 12 underwear; 90% of French respondents have more than 8, and 40% of the Bangladeshi respondents have more than 13. As for the number of underwear ownership, the first place belongs to the boxer-briefs, moreover, the second place is the briefs because the one-fifth of respondents have briefs. The main reasons why the consumers prefer these two kinds of underwear are the low price and the simplicity of the purchasing.

For the Chinese respondents' preferences "descriptive statistics" by SPSS, We can find that boxer-briefs type has the highest average value, it has most of the respondents more like and has many numbers, and each respondent has the lowest difference of choose. Moreover, type of boxer-shorts as secondly. Moreover, for "do not wear underwear", Chinese respondents have an identical preference – dislike.

The situation in purchasing and brand preferences. Chinese respondents (70%), and more than 80% of the others do not have problems before purchasing, and more than 70% of respondents do not ask for help or suggestion opinion. The highest proportion of Chinese, Russians and French respondents bought the underwear in irregularly and per half year; fewer French respondents bought the underwear in per month; more respondents concentrated on the half year and irregularly.

One-third of the Chinese and the Russian, and the quarter of the French respondents have an uncertain situation within their underwear size. Chinese (28.7%) and the quarter of the Bangladeshi respondents do not know which design is more comfortable/suitable for themselves. The Russian (44.1%) and Chinese (28.3%) respondents do not know the appearance after wearing underwear; the French (73.1%) and Bangladeshi (60%) have other problems.

The highest proportions of Chinese, Russians and Bangladeshis respondents have changed their preferences due to their own taste changed, but for near 70% of French respondents, the reason is their income. The line in Figure 2.11 shows the average time between two purchasing of underwear. The highest proportion of respondents has bought the underwear irregularly; fewer respondents bought the underwear in per month; more respondents concentrated on the half year and irregularly.

The purpose of this part is to determine that whether the Chinese respondents have differences in their attitudes toward buying domestic or foreign brands of underwear that can be produced domestically or abroad. In total, only the one-third of Chinese respondents have chosen abroad brands, and a number of Chinese respondents prefer brands, such as C&A, Uniqlo, Zara, H&M *etc*.

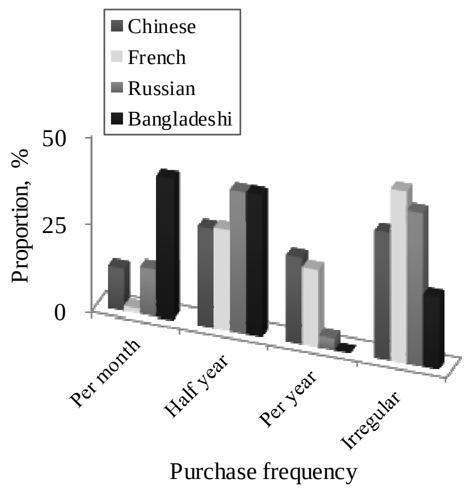


Figure 2.11 – The preferences of purchase frequencies

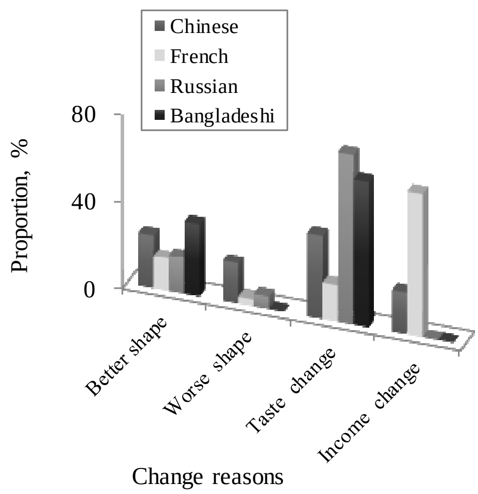


Figure 2.12 – The preferences of preferences change reasons

The number of big and small brands that are operated in the Chinese market of underwear is more than 3000. The number of real developing brands (corporation) does not exceed 400 (Chang, 2017), but the consumers well know about 30 brands or less of men's underwear brand. The Chinese respondents prefer Calvin Klein and Hugo Boss because of its brave and cool design, the affordable price and extensive promotion in China. CK and Boss also have many stores in many Chinese cities and online malls like the biggest online mall of Alibaba’s “Taobao” and “T-mall”. According to market research and survey, the global underwear online market will grow by 17% from 2016 to 2020 [213]. Furthermore, CK and Boss waistband design can be accepted by most young men, most youth or college male students [152]. Many Chinese consumers prefer to use a product with a brand name that has some symbolic identifications [153]. In general, Chinese consumers are unaccustomed or incapable of spending substantial amounts of money on the underwear item regardless of brand name. Though the influence of fast fashion brands such as C&A, Zara, H&M are weaker to the first-line brand, its large quantities of products, as well as faster update product, high speed, and low price, are attracting the vast majority of consumers.

Underwear size. The half of Chinese consumers converge on sizes L and XL, but some sizing systems of men’s underwear brands in China consider L type as the smallest one. So, the values from L to XL approximately fit the bodies with the weight 50...75 kg or the waist girth with 65...80 cm. As shown in Table 2.3 below, we only calculated underwear sizes with a good fit (≥3) for different age groups, the evaluation number are “1 (Very misfit), 2 (Misfit), 3 (General), 4 (Fit), and 5 (Very fit). Aged less than 25 fit the sizes from XL, M to L; Aged 25 to 35 fit the sizes from XL, M to L; Aged 35 to 55 fit the sizes from XL, L to XXL; Aged more than 55 fit the sizes from XL to XXL.

Table 2.3 - Evaluation of size fitness average score

Age groups	S	M	L	XL	XXL
<25	3.52	3.60	3.60	3.68	3.56
25...35	3.48	3.69	3.66	4.04	3.65
35...55	3.61	3.68	3.76	3.83	3.71
>55	2.00	4.00	4.00	4.67	4.25

Std. Dev., ±	0.68	0.76	0.69	0.67	0.67

All Chinese respondents with the excellent fit in sizes XL (mean score is 4.06), but with the age growing, the secondary fit sizes change from M, L to XXL, only a little misfit reflected in a lower level of scores, to improve the size chart, classification of male lower part and underwear structure design is necessary. Besides, nearly 80% of French and half Russian respondents converge on M and L that approximately fit the bodies with the weight 50...70 kg and the waist girth 70...82 cm. Only one-tenth of Russian respondents do not know which size is fitter. 80% of Bangladeshi respondents converge on the XL.

Personal focus factor. Most Chinese, French and Russian respondents focused on the type of underwear. The Chinese respondents are interested in 4 factors (type 24.4%, construction 21.7%, color 21.0% and waistband 20.9%). The French (63.5%) and Russian (34.9%) respondents gave attention to the type and a smaller number of other factors. Because the number of Bangladeshi respondents was limited, the half proportion data are more concentrated on “all elements”. The first and second places belong to raw materials (100 % cotton and cotton + synthetic fibers) of all respondents. Near the one-third of the French and the half of the Russian respondents have no particular preferences about the materials. 20.4% of the Chinese and 28.6% of the Bangladeshi also prefer the materials with Lycra.

The average line showed that all respondents prefer the black color, dark blue secondly, and then printed color. The French customers prefer color blocking secondly, and only 1% of respondents prefer grey color. The least Chinese (4.4%) and Russian (2.69%) respondents were interested in green color. The one-tenth of the Bangladeshi respondents prefer green colour and do not prefer red, white and colors.

3. Physiological (feeling of wearing) of underwear. Underwear functionality demand. As we can see in Table 2.4, most respondents focused on the underwear comfort and the function.

Table 2.4 – The proportions of uncertain situation in purchasing underwear, %

Main attention	Chinese	French	Russian	Bangladeshi
Comfortable	**25.1**	**77.0**	**60.0**	**100.0**
Attractive appearance	12.1	8.1	13.3	0.0
Correction effect in front	23.4	0.0	3.3	0.0
Correction effect in back	14.9	0.0	3.3	0.0
Correction effects in both	17.0	1.4	13.3	0.0
Unconsidered	7.4	13.5	6.7	0.0

Near the quarter of the Chinese respondents are interested in the correction effect in the front part (genitalia). Near the one-tenth of the French and the Russians focused on own appearance in underwear. They also attach the type of underwear and other elements, such as color, construction, and waistband design to help improve the appearance.

The correction effects are chosen by the Chinese respondents who prefer underwear with "Many seams". Through our analysis of variance and post-hoc test of Scheffe's method, we can see that the three dependent variables of the *F* values of the overall test are 6.81, 3.14 and 4.97, all *Sig.* < 0.05, both of them reached a significant level in Table 2.5. Therefore, the differences exist between correction effects in "front", "back" and "both" about the respondents' preference of "Many seams", and the differences among the matching groups reached significantly. According to the mean difference (I-J); we can see that

- For prefer correction effect in front, respondents "Very like" ("Like") underwear with many seams more than "Dislike" and "General", no major fluctuations, means they prefer underwear with many seam and correct front;
- Correction effect in back, they "Very like" underwear designed many seam lines to correct hips more than "Dislike";
- Correction effect in both, mean difference (I-J) is 1.08, means they "Very like" underwear designed many seam lines to correct front and hips, and there are significant differences with "Dislike".

Therefore, in total, the respondents like underwear with "many seams" and prefer correction effects in front and back similarly.

Underwear wearing way. Bangladeshis (60%) prefer to wear the pants (waistband lower than the underwear waistband) to expose the underwear waistband. Majority of the other respondents wear the underwear below the pants waistband to cover the underwear (Chinese 70.0%, French 63.5% and Russian 53.3%). 53.2% of the Chinese consider the matching degree of underwear and pants each time, such as wearing tight jeans with tight underwear or small size underwear. 79.7% of the French and 50% of the Russians never consider the underwear and pants as in the same style when they change different pants with underwear unchanged. 80% of the Bangladeshis do not consider the underwear and pants style match.

Table 2.5 - The analysis of variance and post-hoc test

Dependent Variable	Multiple Comparisons (Scheffe)					
	(I) Many seams	(J) Many seams	Mean Difference (I-J)	*Sig.*	95% Confidence Interval	
					Low	Up
Correction effect in front (genitals)	Dislike	Very like	-0.89	0.03	-1.72	-0.07
	Like	General	0.46	0.04	0.01	0.90
	Very like	General	0.86	0.00	0.28	1.44
Correction effect in back (hips)	Very like	Dislike	0.89	0.03	0.07	1.72
Correction effects in both	Very like	Dislike	1.08	0.00	0.28	1.89

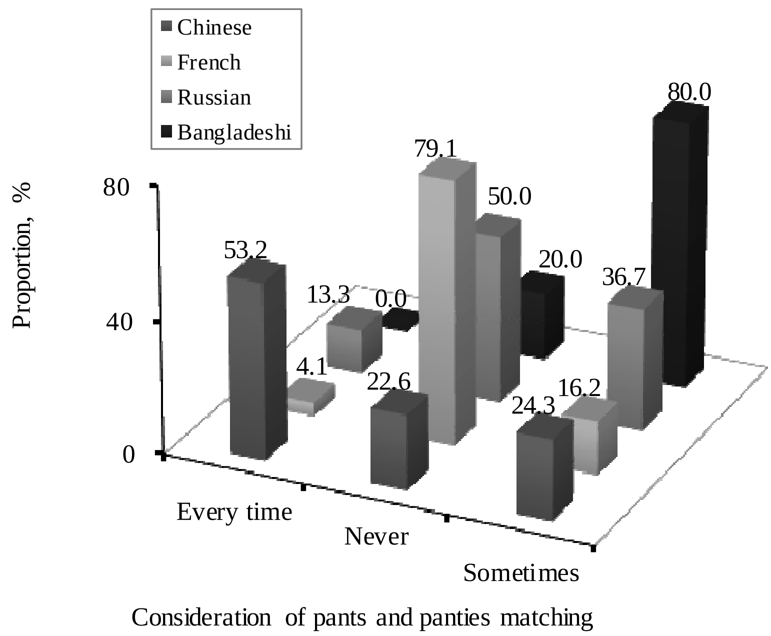


Figure 2.13 – The preferences of underwear and pants match

According to the survey, most of the respondents wear underwear all day French. 60% of Bangladeshi respondents prefer to sleep naked. Russian, Chinese and French is more similar to the underwear wearing frequency.

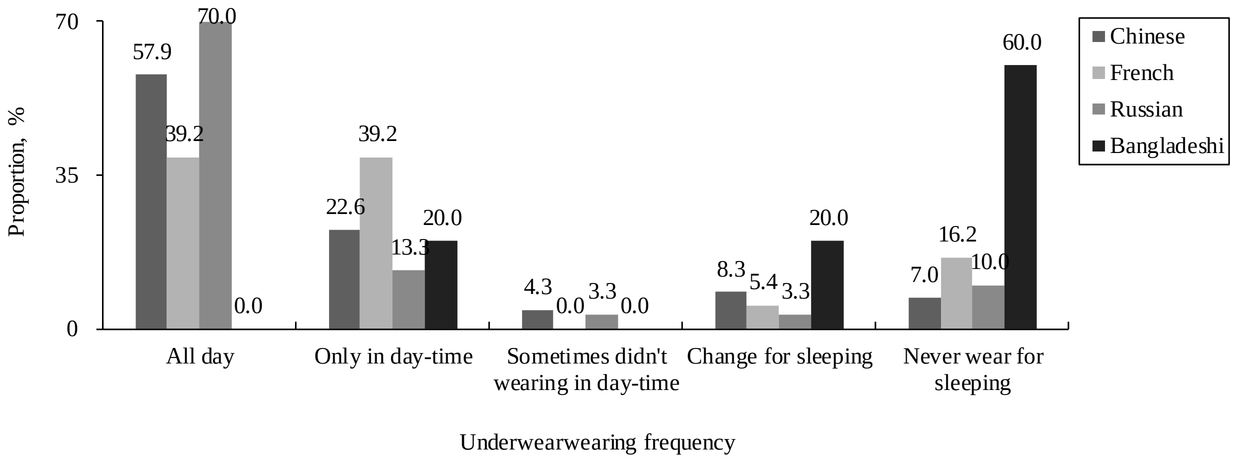


Figure 2.14 – Distribution of underwear wearing duration

Positions of uncomfortable feelings. All consumers have a perception of uncomfortable feeling that mainly caused by a structural problem in the front area and the crotch area of underwear (27% Chinese, 48.6% French, 23.7% Russian and 20% Bangladeshi); most of the Russian respondents feel uncomfortable from the material. However, more significant feedback proportions point that the unreasonable underwear structural design and underwear size will cause many problems.

2.3.3. General preferences

The most important component factors of consumer behaviour preferences are underwear type and functional (structural line) design, including type, tightness, and structural line. The secondary factors are purchase frequency, underwear brand and feeling of wearing, including, comfort demand, fit size and material, color *etc*.

The boxer-briefs are the leader of preferred and own products, the boxers, the boxer-shorts and the boxer-briefs represent more than 50% of the total purchases. In fact, the boxer-briefs are the most advanced product in the market due to its simple style and appropriate tightness, so it will be necessary to do specific research and analysis on this product. The respondents' favourite design is the underwear with few structural seams, the position of waistband below the nature waist 5...7 cm, push-up function, 100% cotton, and dark colors.

The quarter of respondents do not know which design they prefer. The one-third of respondents could not identify their underwear size; it indicates that contemporary men's underwear does not have a clear description about its structural characteristics, function, and the consumers do not have particular awareness and experience. So, new functional and structural underwear need to be studied and discussed. The materials and structural design cause the uncomfortable feeling of most respondents. The half respondents like underwear with the push-up effect.

Summary of chapter 2

As a result of the study, differences between consumers and problems arising from the purchase and wearing of underwear were established.

1. Based on the conducted artistic and constructive analysis of men's underwear on the market, the main types of underwear and their structural content were determined. The positions and configuration of the main lines – belts, bottoms, design of the front inserts, which became typological spaces for the development of new design of functional underwear.

2. Underwear sizes concentrated on M, L and XL with 65...82 cm waist girth and the 50...75 kg weight. The respondents generally owned 8...12 pieces of underwear. The purchase time of underwear is mostly untimed, but it is usually half a year. It can be seen that men's underwear has a large potential market.

3. Most consumers prefer boxer shorts and boxer types with a small number of stitches and consider comfort as the main indicator. There is a high interest in compression underwear. Chinese consumers prefer very dense underwear with a large

number of stitches and corrective effects. As a consequence, it is necessary to study the structural design of tight-fitting boxers and boxers and to improve their comfort.

4. The most problematic area in the underwear is the front part and the contact area with the crotch. This suggests that the structure of underwear is not adapted to the morphology of the human body. Thus, the study of the structural characteristics of men's underwear and the ability of knitted materials to provide the necessary effects is essential to the satisfaction of consumers.

Thus, the design of underwear, which is the result of knowledge of the morphology of the male body, the correctness of the manufacture of drawings and the assembly of materials, is the most important point.

Chapter 3. ANTHROPOMETRICAL DATABASE FOR UNDERWEAR DESIGN

3.1. Features of male body morphology

3.1.1. The effect of the morphology of the lower part body and the structure of underwear

In the design of male pants often add a certain amount of ease, short-pants are directly changed from pants. Therefore, it is conceivable that the underwear may also be drafted by the pants prototype, and change the fabric, reduce the ease, adjust the crotch and add the structure of the front pouch, to make it completely wrapped (closely) the body. Crotch part is an essential structure parameter of the male body, and also an important part of the underwear movement area. Its structural changes directly affect the aesthetics, comfort and functionality of the underwear (or pants) [58]. The front crotch width and crotch width of the underwear structure, according to the fabric flexibility, usually have negative ease.

a) The relationships between legs type (shape) and underwear affect the width of the crotch between the thighs in the femur: X-type legs often make the crotch gap narrow (width in positive perspective), but pelvic wider. Thus the outer side of thighs will have a tight feeling when wearing the typical structure of the underwear (pants); O-type legs often make large trochanters and thighs to both outward sides, and crotch gap bigger (Figure 3.1a).

b) Figure 3.1b shows value “*a*” is the horizontal crotch width between the two thighs, which can define the width of the underwear crotch for design. If two underwear have the same values of “*a*”, one male with the crotch width between thighs is greater than the values of “*a*”, the underwear crotch will be more smooth (or loose) without fold. If on male crotch width is less than the distance “*a*”, the underwear crotch part will have ma folds.

c) As shown in Figure 3.1c, in the case of the same waist girth, the hip and thigh girths change to make the underwear outline styles change: “A” style is for the normal standard body underwear. “B” style has the constant hip girth but smaller thigh girth, we can see that narrowing the width of the bottoms. “C” style reduced the hip, and thigh girths based on “B”, the outline of underwear sides is near to vertical. “D” style increased hip girth, the underwear widened. “E” style increased value of the hip and thigh girths; the underwear appearance was like a trapezoidal.

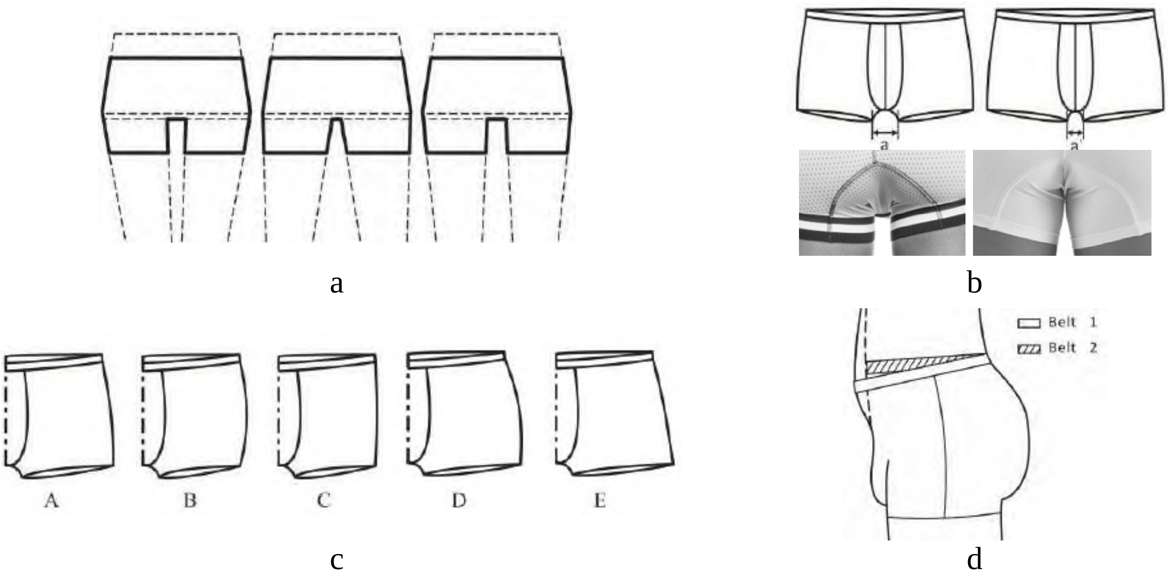


Figure 3.1 – Influence between body and underwear: a – comparison of different legs types X-type, O-type, normal type; b – comparison of crotch part; c – proportion of girths; d – bodies with different abdomen bulge

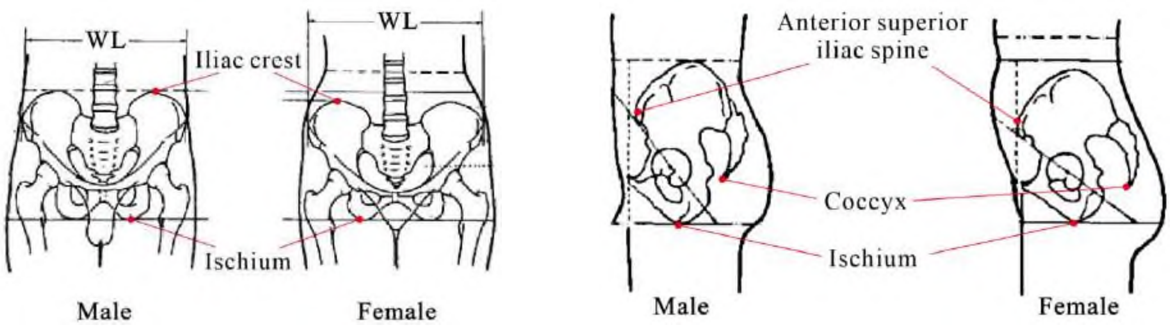
d) As shown in Figure 3.1d. The bulge of lower abdomen affect the girth allocation in waist front and back, the lower abdomen bulge sometimes is defined by the difference between overweight and underweight body shapes. Due to a large proportion of soft body tissues in front of the waist and abdomen, and the back lower buttocks. Therefore, the front abdomen part is primary considered mostly for underwear waistband design. “Belt 1” in Figure 3.1d can be seen that the ratio of front waistband girth is larger than back, and usually the position move lower than the maximum girth of the bulge part, which conforms to the wearing preference. "Belt 2" is the basic style.

3.1.2. Pelvis features

As shown in Figure 3.2, the difference of thickness (profile width) of the waist and hip of the human body determines the difference of the crotch width (profile width) between male and female. The distance between the ends of the sacrum and the ischium of the female is larger than male, resulting in differences in their hip shapes. The distribution of soft tissues in the buttocks is different, for a female they are lower and more, then make buttocks flat and sagging, for male are less and upper, so raise buttocks. Using the 3D body scanner, 127 young females was measured and got profile sections, the average thickness of female hip level is 22.56 cm, and 115 young male average thickness of hip is 24.87 cm. As can see, the average hip thickness of male is more significant than female. Also, the female' tilt degree of the sacrum, the difference between hip and waist girth and the pelvis is wider than the male, so the angle of the back center line for women's pattern block is larger than the male [139, pp.62-63].

As for lower torso profile section in Figure 3.2a, the thickness of two peaks between waist and hip "*a*" are closely relate to crotch width of pants (underwear) in pattern block (same as "FH" to "BH", the profile crotch width), but the thickness is not equal to the crotch width. When the thickness of "*a*" is large, that is the large size of the body, the crotch width "FH-BH" should be appropriately increased; when the thickness "*a*" is small, is the small size of the body, it needs to reduce the crotch width "FH-BH" properly. FH – the first point at the hip level, BH – the back point close to sacrum or coccyx in the hip level, not on buttocks. FH to BH is the body crotch wide, FH', BH' are corresponding FH, BH in the pattern blocks. The values of "b" and "c" are directly related to the distance from FH to BH (Figure 3.3).

As shown in Figure 3.3c, FH and FH' not overlapped, BH and BH' are near, there is a certain amount between the distance of FH'-BH' with FH-BH. The front crotch width (FH-*Cr*, *Cr* is crotch point) is “b” in Figure 3.3c. FH point changes decide the “b”, also decides the crotch ache curvature from FH to *Cr*; this radian affects the front crotch width “b” value. About the “c”, that is the BH point to crotch point *Cr* horizontal distance.

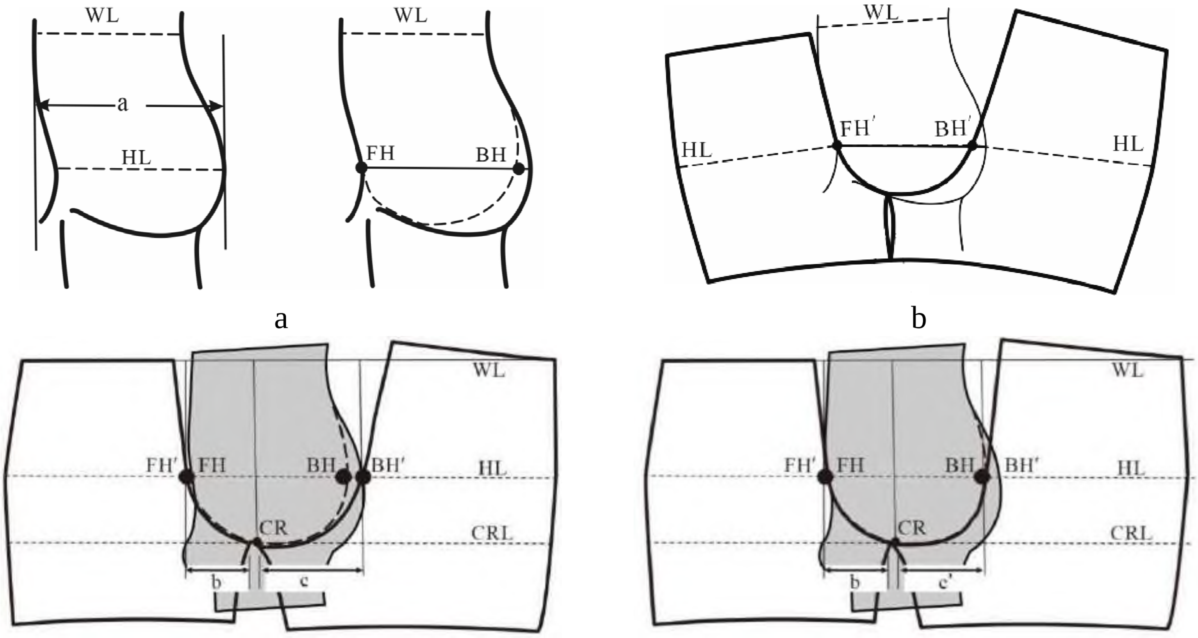


a b

Figure 3.2 – Comparison of male and female pelvis: a – front pelvis; b – profile pelvis [139, pp.202]

As shown in Figure 3.3d, according to the shape of the lower torso and drawn a fully fitted body structure pattern block. So that the front and back of the crotch arc and the human body crotch arc line very closely, that is FH-BH = FH'-BH', FH and FH, BH and BH' overlapped.

From the above in Figure 3.3c, we can see that FH'-BH' on pattern larger than FH-BH on the torso, and two Cr points (peaks) on pattern blocks in CrL front and back are not overlapped. If overlapping the two Cr points (peaks) like in Figure 3.3b. Then make the front and back HL are forced to be horizontal with FH'-BH' line like in Figure 3.3d, the distance of FH'-BH' will be shorted and as same as FH-BH (the distance of “c” also shorted to be “c'”). So, to design the pattern block, the distance of FH'-BH' should be less than the actual FH-BH distance of the human body when overlapping Cr points. That is, the crotch width (b' + c') should be less than the thickness of profile section of the waist to the hip of the human body, to maintain a stable (tight-fitting) fitness. In the underwear design, it is necessary to be kept in good fit condition.



a b

c d

Figure 3.3 – Relation of body profile and pants crotch: a – the thickness of profile sections; b – profile section with pattern; c – pattern with ease at BH; d – comparison with pants pattern

3.1.3. The features between waist and thigh

The waist is the thinnest part of the body, is the body's baseline in horizontal section, and is the body upper and lower parts' torsion zone. The full name of waist girth is natural waist girth, it is the smallest girth of the waist part and the shape is similar to an ellipse. However, different styles of clothing have different waist position(high or low), so it is necessary to take the actual design of the waist girth into account, such as low waist pants, low waist underwear, high waist skirt and so on. In men's pants design, the waistline is usually lower than the natural waistline, and the waistline value cannot be only based on the natural waistline W_G (waist girth) as a reference, should be based on waist girth measurements closest to the waistband. For example, the line 4 cm below natural waistline (near anterior superior iliac spine) is usually called mid W_G (mid-waist girth), or below 8cm called low- W_G (low-waist girth).

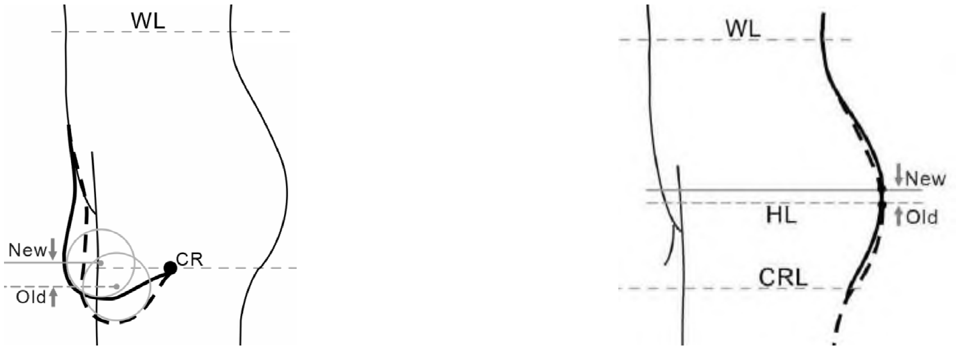
Buttocks are the most changeable part of human body movement, because of walking, squatting and other actions, make the buttocks skin more stretch. The hip subcutaneous fat layer is thicker and more concentrated in the gluteal groove at the bottom of the hip. Which led to the overweight of the human body shape with age, fat deposition and body shape change, the hip shape gradually drop. Which will directly affect the fitness at hip part of pants (underwear). Therefore, the underwear that corrects (lifts) the effect appears. The abdomen is an important part of the male body (abdomen muscle, meridian line). The abdomen girth of the normal standard body is usually between the waist and the hip girth, that is, the middle and low waist girth area. The abdomen is the soft tissue structure without skeletal support, so the negative ease depend on the elastic fabric properties are usually used to meet the body fit.

As for leg and crotch part, legs girth directly affects the value of underwear bottom. The crotch area is the bottom of the torso, between two thighs. In the underwear design, the crotch should be tightwithout fabric folds, and this area to a large extent determines the comfort of underwear.

3.1.4. The push-up effect

Figure 3.4 shows the lifted effect of soft tissue in the front and back; we drew two circles around the male genitalia, and measured the center height of the circle to represents its height. a – “old” is original height, “new” is height after lifted. It can be seen the amount of lifted space for male genitalia is relatively large, and the amount of soft tissue for hip promotion is relatively limited.

The main effect of men’s underwear is correction effects (push-up effect), As shown in Figure 3.4a, before (dotted line) and after wearing underwear, the male genitalia and buttocks soft tissue height are lifted a certain distance, and different styles have different lift degree. This set of 12 samples were measured in *Anthroscan* software to measure the center of the base due to the experimental factors (nudity).



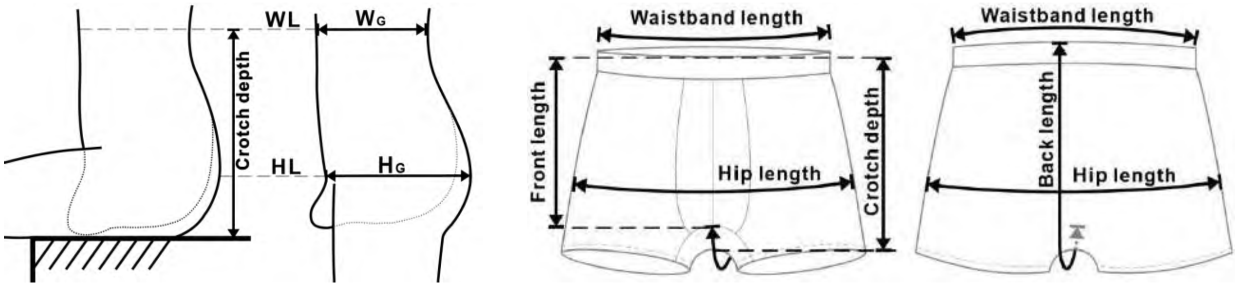
a b

Figure 3.4 – Push-up effects for body morphology correction: a – push-up effect of front; b – push-up effect of back

3.2. Methods of exploration of anthropometric database

Nowadays, men's underwear is designed on the base of traditional-using body measurements (such as waist girth, hip girth, weight or height) and labelling as M, L, *etc* [268]. Sometimes the sizing systems and the charts are differing between national brands and underwear styles due to the different geographic traditions [72]. Moreover, the similar ways of underwear labelling and male body grouping are not enough to present the garment features and different styles [171]. The consumers with distinctive physiological characteristics and untypical body measurements usually use one size charts, and underwear cannot be tried-on before purchasing to control the fit and the comfort. So, under the general process of customisation, the consumers need more information about the specific features and the construction of underwear to be confident about the wearing comfort, the functionality, and many other aspects.

The current existing pattern drafting methods of men's underwear is very incomplete, based on empirical data and finished garment measurements without the equations which combine the pattern block parameters and the body measurements in according with the male body morphology. For these reasons, there is no accurate, detailed, scientific pattern drafting method of men's underwear prototype. Figure 3.5 shows the scheme of traditional measurements taken from the body and the underwear.



a b

Figure 3.5 – Traditional measurements: a – measurements are using for body presentation; b –control of ready-to-wear underwear

As shown in Figure 3.5a, there are three primary body measurements such as the natural waist girth W_G (narrowest, smallest girth at waist level *WL*), hip girth H_G (largest girth at hip level *HL*) and the crotch depth (the distance between *WL* and seat level). The crotch depth has been measuring in sitting position, and it is affecting by soft tissues of buttocks. As shown in Figure 3.5b, there are five measurements to control the fit of ready-to-wear garments such as the middle length (divided between the front and the back), the crotch depth (from the waistband to the bottom), and waistband length and hip width. This list of measurements is not equal to the body measurements, and the knitted material properties will be affecting the values.

Therefore, to create a new method of men's underwear pattern block drafting, we need the additional information which allows increasing the customer satisfaction, to produce the underwear more close-fitting and comfortable, to reduce the production cost [105]. Instead of using only the sizes of ready-to-wear underwear, such as waistband girth and full crotch length, some new additional measurements should be added to describe the male morphology [5, pp.17-33]. So, the improvement of underwear cannot be made without structural changes to databases.

In our prior exploration, we collected the judgments and demands of more than 700 males from China, France, Russia and Bangladesh. Most respondents have stressed by underwear size, type and front crotch; moreover, the majority of respondents also said that simple way of underwear labelling (such as M, L…) does not give them a right choice to buy underwear. So, the traditional body sizes for labelling and design of underwear are outdated and unreasonable; it should be readjusted and reformed.

3.2.1. 3D body scanner for experiment

Anthroscan is a software for the visualisation, processing and evaluation of 3D scan data, in general, delivered by the *Vitus Smart XXL* 3D body scanner. *Anthroscan* interactive measurements are used in place of the anthropometric measurements for all practical tools for the human body. Each dimension of the body has a separate four-digit code/number, such as *7525* is hip girth.

a b c

Figure 3.6 – 3D scanning systems: a – 3D body scanner; b – scanning standard; c – scheme of measuring of traditional; d – new body dimensions

In early experiments, we have made a more comprehensive and integrated analysis on men’s underwear comfort and structural design. We have obtained some basic theories about men’s underwear and crucial dimensions data which provide a basis for subsequent experiments [274-281].

Two methods titled as "traditional" and "new" are used to measure body sizes. The first ones were obtained directly by 3D body scanner; the second ones were calculated from horizontal and vertical cross-sections extracted from the full-size digital images by processing and analysing. In two ways, we combined characterised measurements to create a new classification of male bodies.

Sagittal plane – vertical plane divide the body into right and left sides; mid-sagittal plane bisects the body at the exact midline. Coronal or frontal plane – divides the body or organ into anterior and posterior portions. Transverse plane – divides the body or organ into superior and inferior portions (may also be called cross-sectional or horizontal plane)

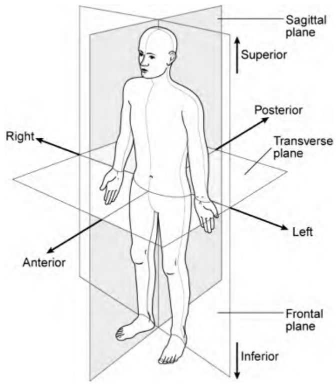


Figure 3.7 – Plane or section imaginary flat surfaces that pass through the body [168]

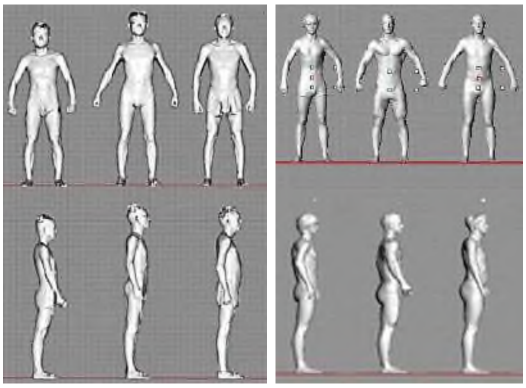
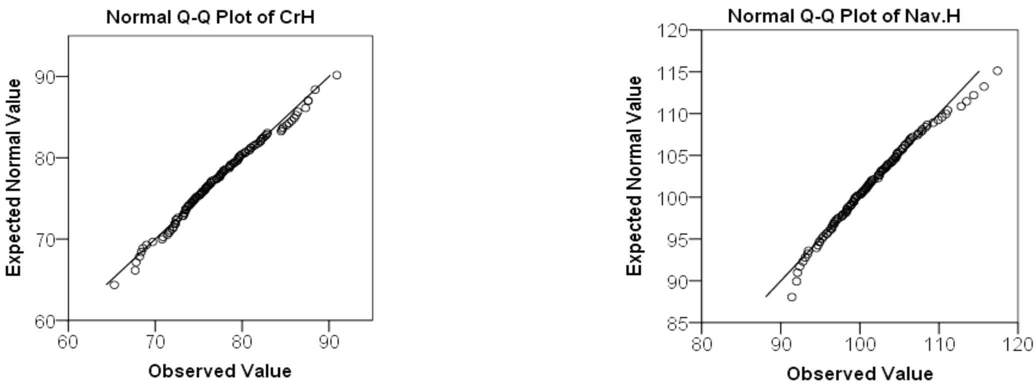


Figure 3.8 – Samples models, Chinese and Russian

Youth males were chosen including 115 Chinese, 7 Bangladeshi and 38 Russian (18 to 28 ages) without structural deformations of the locomotor system. So, the total value is 160 young male with the considerable part of Chinese males. By our measure, the primary data of body measurements of the Chinese are the height is from 156.1 to 206.7 cm, the natural waist girth is from 63.5 to 93.3 cm, the hip girth is from 82.8 to 114.1 cm, the crotch height is from 65.3 to 90.9 cm. The similar values of Bangladesh and the Russians are the waist girth is from 85.3 to 99.2 cm, the hip girth is from 78.6 to 100.7 cm, the crotch height is between 77.3 and 79.1 cm. To prove the total value of measured males and to decrease the cost and time of our experiment, we suggested that the body sizes of measured males obey the normal distribution.

In most anthropometric applications, the number of measured people should be bigger than n ≥ 30 [144, pp.179-200]. However, if the number of objects obeys normal distribution, the smaller value can be used to get the accuracy results. We controlled the number of all body measurements measured to be sure about its belonging to a normal distribution. We used Shapiro-Wilk (*S-W*) test of the most powerful normality test by SPSS [155], *S-W* test can provide better power than the *K-S* test [175]. Researchers recommend it as the best choice for testing the normality of data [187, pp.143], and we also check normality visually by the effective diagnostic tool of *Q-Q* plot [53, p.822].

For example, Figure 3.9 shows the significant normal distributions of *Q-Q* plot (also with small deviation) of two body dimensions, for our large sample sizes, the *Q-Q* plots are easier to interpret in case of large sample sizes, the even small deviation will not affect the results of a parametric test.



a b

Figure 3.9 – *Q-Q* plots: a – crotch height; b – navel height

As Figure 3.9 show, the both *Q-Q* plots of crotch height and navel waist height prove that 115 measurements of Chinese males obey normal distribution, so n = 115 is enough [46]. The same conclusions have been made about other measurements. So, 115 young Chinese males can represent the population chosen.

We used *VITUS Smart XXL* (3D body scanner) by the scanning standard DIN EN ISO 20685 to do the measurements and *Anthroscan* (3D image processing software) to determine the relevant body measurements interactively. *SPSS* software has been used for data analysis. *CorelDraw*, *Photoshop* and *Rich-peace CAD* have been used for the visual presentation of image processing and structure design.

3.2.2 Determination of the crotch point

The measurements at crotch part of sagittal sections can be measured by body scanner and marked as (Figure 3.10): ***6010*** – Full crotch length, from the natural of the waist front, cross the crotch point, to the natural of the waist back (the length based on the body center), a full arc through the groin area of the *CL*; ***6011*** – Front crotch length (CL_F), from the natural of the waist to the crotch point (the length based on the body center), the arch through the groin area in front of the CL_F; ***6012*** – Back crotch length (CL_B), from natural waist back to the crotch point (arc through the inguinal area behind CL_B.

We have chosen the vertical cross-section taken from crotch point as the main informative resource about the male torso morphology. An overlapping method has been used to find out the difference between the cross sections of the male lower body. At first, we have cut the standing body in the sagittal plane by *Anthroscan*. It should be noted that this profile cross-section at the posterior part almost close to the vertebrae and at a hip level close to the sacrum. So, soft tissues, muscles and skin have the limit affected especially at seventh cervical (*C7*), natural waist back point (*WB*). All reference points can find out from the data by *Anthroscan (Scanworx)*.

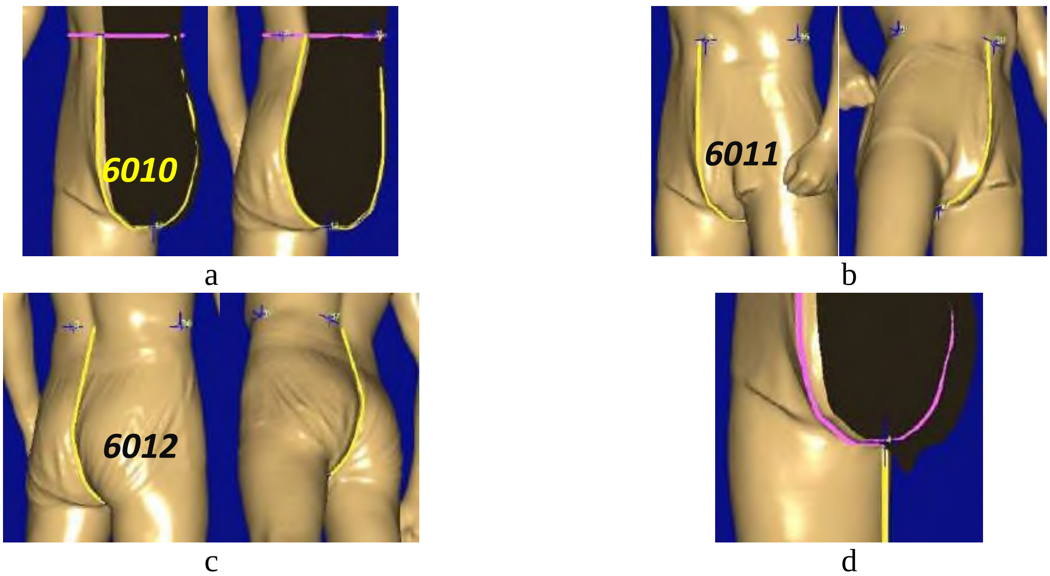


Figure 3.10 – Measurements at crotch: a – *CL*, b – CL_F, c – CL_B, d – Cr point by scanner

To overlap the profile cross-sections, we should find the location of crotch point (*Cr*), that is similar as the perineum under the lower torso and between thighs [150], and it corresponds (closest) to the ischium position and effects by the tilt angle of the whole pelvic in anatomy. There is two-point connection line of the iliac crest and ischium which represents the tilt of the innominate bone [122]. As shown in Figure 3.11b, the larger posterior pelvic tilt, the larger lumbar kyphosis and sacrum downward; the larger anterior pelvic tilt, the larger lumbar lordosis and sacrum upward [257].We knew that the tilt changing of the innominate (pelvic tilt) affects the direction of the sacrum, the normal spine (normal standing posture) is *C7* vertical guideline a little offset (anterior) from the superior of sacral promontory. As Figure 3.11b shows [56, 2], we can see the positions of *Cr* but it is difficult to define *Cr* accurately by means the body scanner for next misleading factors. Such as the limitation for light penetration between two thighs, the underwear influence, the genitalia position affected by underwear design, and the standing habits. All factors caused the differences between the human body shapes in the sagittal plane. Figure 3.11a shows the new method we proposed to find the location of *Cr*.

Firstly, we drew two straight lines: the line “*a*” is starting from *WB* and tangents to the middle-lower section of the thoracic vertebrae; line “*b*” is going through two points from *WB* to the end of sacrum or coccyx as the peak point on hip level. These two lines confirm the contour characteristics of thoracic vertebrae and sacrum (or coccyx).

Secondly, we found out the middle point of natural waist width in sagittal plane by dividing the width in half. Thirdly, we drew two new lines “*a*'” and “*b*'” in parallel to the line “*a*” and the line “*b*” through the middle point of natural waist width, so, three lines have formed the crossover point. Fourthly, we drew the line from the crossover point down to the bottom of profile section to divide in half the angle between the line “*a*'” and the line “*b*'”. Finally, *Cr* (black point) has been defined as the endpoint of bisector line which is starting from the cross-point of “*a*'” and “*b*'” on natural waist level.

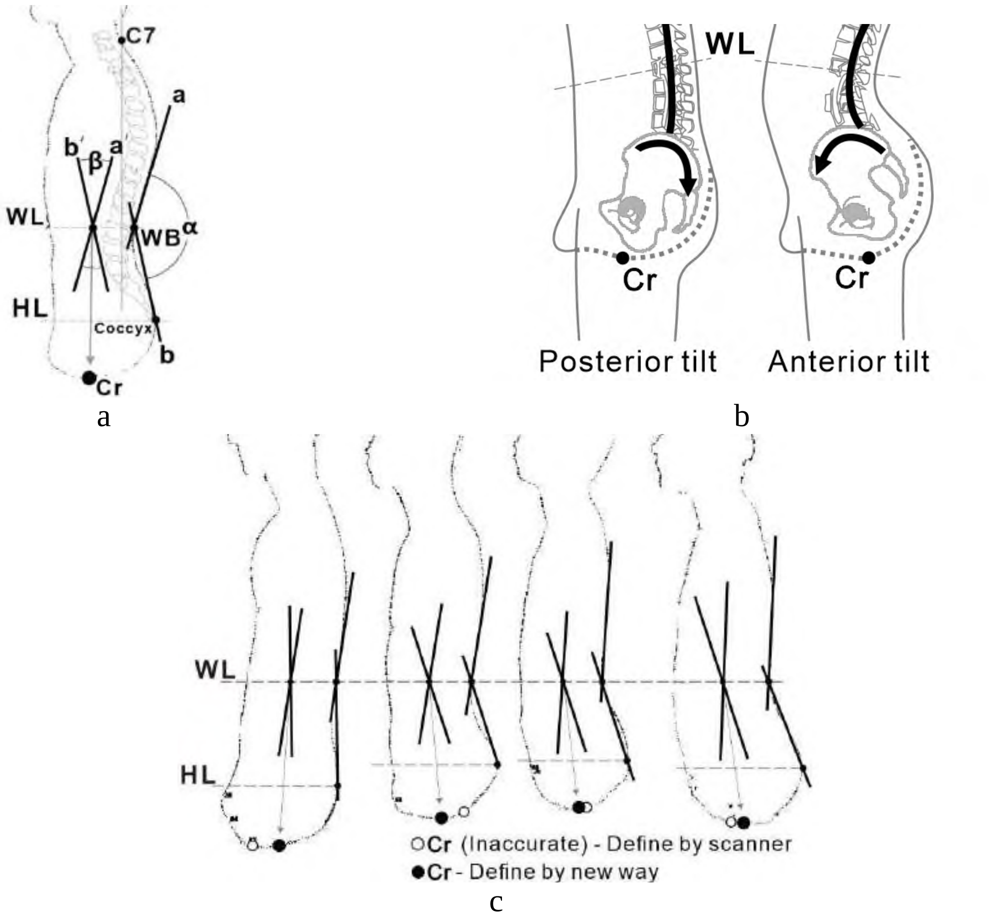


Figure 3.11 – Scheme of a vertical cross-section taken from the real scanned body: a – new method of point *Cr* finding out; b – pelvic tilt; c – comparison of point *Cr* locations for four bodies.

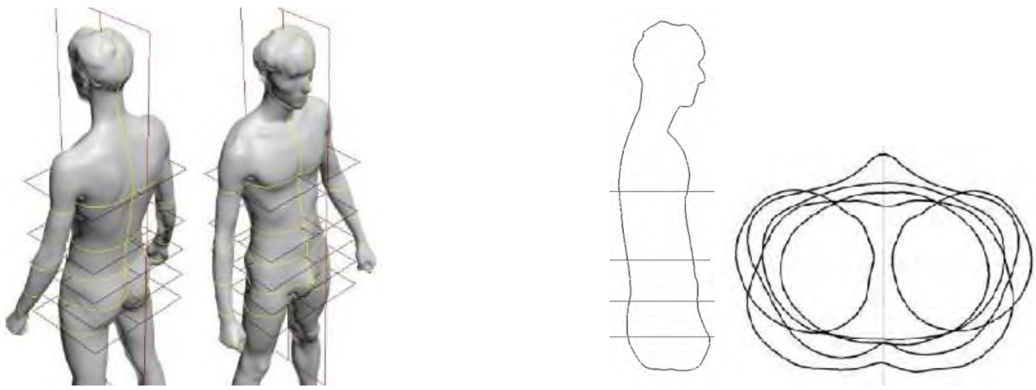
Figure 3.11c displays some profiles which were generated from the scanned bodies with their morphological characteristics such as different genitalia bulges, sacrum bulge, upper torso (vertebrae) and different height and profile thickness (small or big). We can see the apparent difference between two locations of point *Cr* - new (black color) and old one that was defined by the body scanner (white color). Anthroscan has found old point *Cr*. The old *Cr* points located near genitalia or buttocks are unreasonable, machine measurement error causes it. However, new points *Cr* is located entirely in the more accurate positions that do not depend on the body shape, male genitalia and buttocks bulge.

The point *Cr* is a significant anthropometrical point, and the problems of its identification by standard measure appear from the delicate situation. Our method has been tested one-by-one in our database which contains the human bodies with different shape characteristics, and the results are more accurate than after the machine positioning. This method combines the knowledge of human body morphology and s medicine science.

3.2.3. Overlapping the profile cross-sections

As Figure 3.12 shown, the extract method of the profile sections.

As shown in Figure 3.12a, b are the way to cut the models and find the center vertical line to depart the lower torso in profile and then find the *Cr* point in next section. To overlap the profiles sections of the lower torso that were taken from scanned bodies as shown in Figure 3.13.



a b

Figure 3.12 – Male body model: a – cut sections; b – porfile section and crosss-sections of thigh, hip, abdomen, waist and bust

We used two axis - the horizontal axis as natural waistline (*WL*) and the vertical axis from point *Cr*. Firstly, we drew the vertical line drown from point *Cr*. Secondly, we put all natural waistlines which were found out by software *Anthroscan* together to one horizontal guideline. To adjust all profile sections, we adjusted them according to two rules: first, to put all *Cr* points on vertical guideline; second, to put all waistlines on horizontal guideline.

3.3. Formation of a new anthropometric base

3.3.1. Parametrize profile sections through the crotch area

By this way, we have joined together all profile sections. Figure 3.13 shows the scheme of a method of finding the average cross-section which we have developed taking into as an example of cross-sections of the Chinese.

Firstly, we have drawn four vertical fixed-lengths from *WL* downward to the level of *Cr* equal to values calculated before;

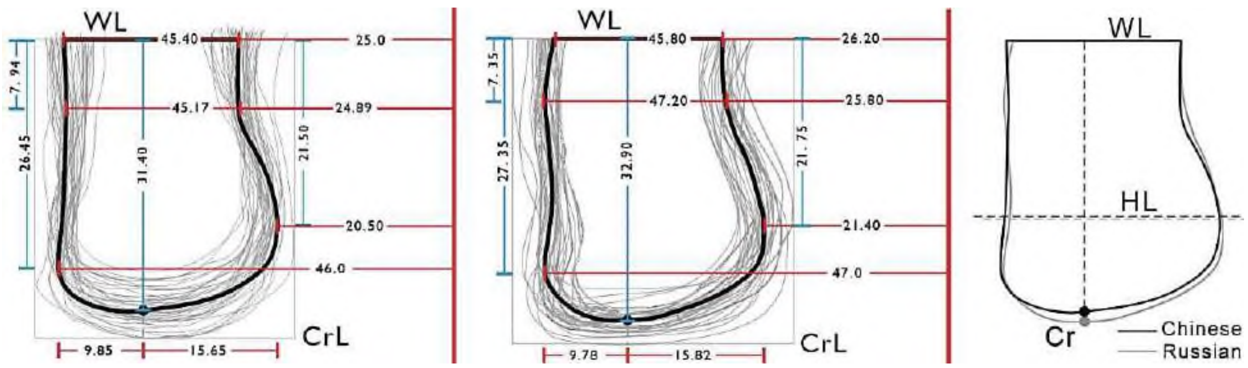
- The median (50th percentiles, *Q2*) distance to the level of maximum belly (at profile perspective) circumference (7.94 cm);
- The median distance to the level of genitalia peak point (26.45 cm);
- The median of *BR* length in according with *Cr* vertical line (31.40 cm);
- The median distance to the level of buttock peak (21.50 cm).

Secondly, we have drawn six horizontal fixed-lengths from the vertical guideline equal to values calculated before:

- The median distance to natural waist front (45.40 cm) and back (25.0 cm);
- The median distance to maximum belly front (45.17 cm) and back (24.86 cm);
- The median distance to genitalia bugle (46.0 cm);
- The median distance to hip bugle (20.50 cm).

Across seven points we drew the average vertical cross-sections for the Chinese males (Figure 3.13a). The same method we used to draw the Russians' median profile sections (Figure 3.13b).The characteristics were measured from the profile sections after overlapping as Figure 3.13c shows.

Table 3.1 shows the characteristics that were measured from overlapped profile cross-sections. To get the overlapped figure of profile cross-sections in Table 3.1, we joined the *WL* as the top reference line and aligned the *Cr* points to a vertical line. The differences *1* belong to the Chinese; the differences *2* belong to Bangladesh and the Russians. We can see the big differences exist between the considerable parts of overlapped lower torsos: between the front bulge and buttocks; between the peak levels of hip and genitalia.



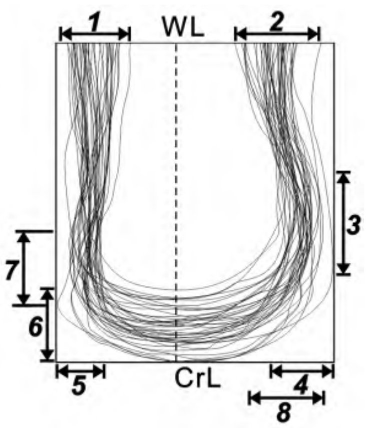
a b c

Figure 3.13 – Overlapped profile sections of lower torso: a – the Chinese; b – the Russians; c – median profile sections of the Chinese and the Russians

Some differences of Bangladesh and the Russians are smaller than the Chinese, but the difference *No.5* (genitalia bulge) is more significant. In totally, the fundamental differences are *No.3, 5* and *7* and the all are crucial for functional underwear especially with “push-up” effects and lifting of hips soft tissues and front genitalia.

To analyze the possibilities of the male torso to reshape and get “push-up” effects by pressing the soft tissues, 15 males without underwear (nude) and with underwear (in daily underwear) have been measured. 15 volunteers have participated in this experiment with written permission to scan naked but did not disclose the body models and names. To analyse the effect of soft tissues lifting, a curved line has been drawn including the testicles and the penis to regard as a circle (or round spheres), so this part can be lifted upward by different underwear with particular range. Through our tests, the average lifted distance in front genitalia is from 2.1 to 8.8 cm, in hips soft tissues is from 0.2 to 1.1 cm.

Table 3.1 – The cross-sections of male’ lower torso and places with maximum difference

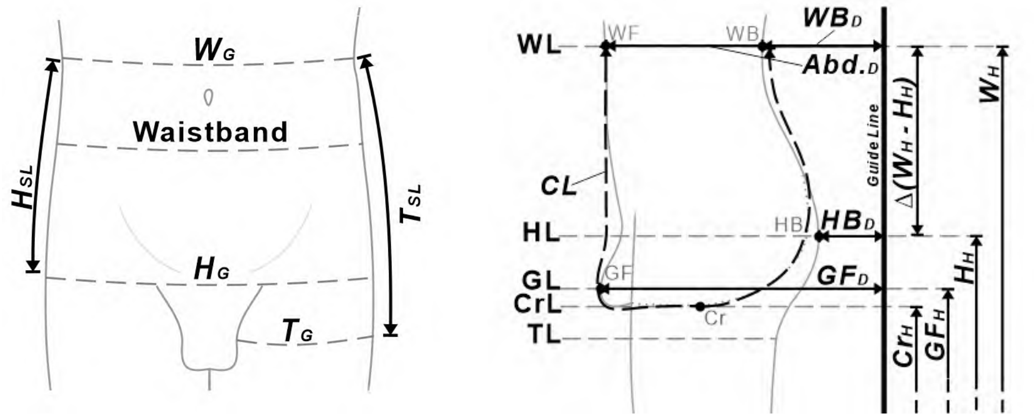
Overlapping cross-sections	No.	Place of differences located	Difference *1*, for the Chinese	Difference *2*, for Bangladesh and Russians
	*1*	Natural waist front	6.9	8.6 / 2.4
	2	Natural waist back	9.8	1.6 / 1.7
	3	Hip peak level	11.5	10.8 / 3.0
	4	Hip back	4.7	4.9 / 4.5
	5	Genitalia bulge	5.4	8.3 / 5.6
	6	Crotch height	8.1	10.8 / 5.6
	7	Genitalia peak level	11.7	14.8 / 7.9
	8	Natural waist depth Back	1.1…8.8	3.2…4.3 / 3.2…9.1

3.3.2. New body measurements

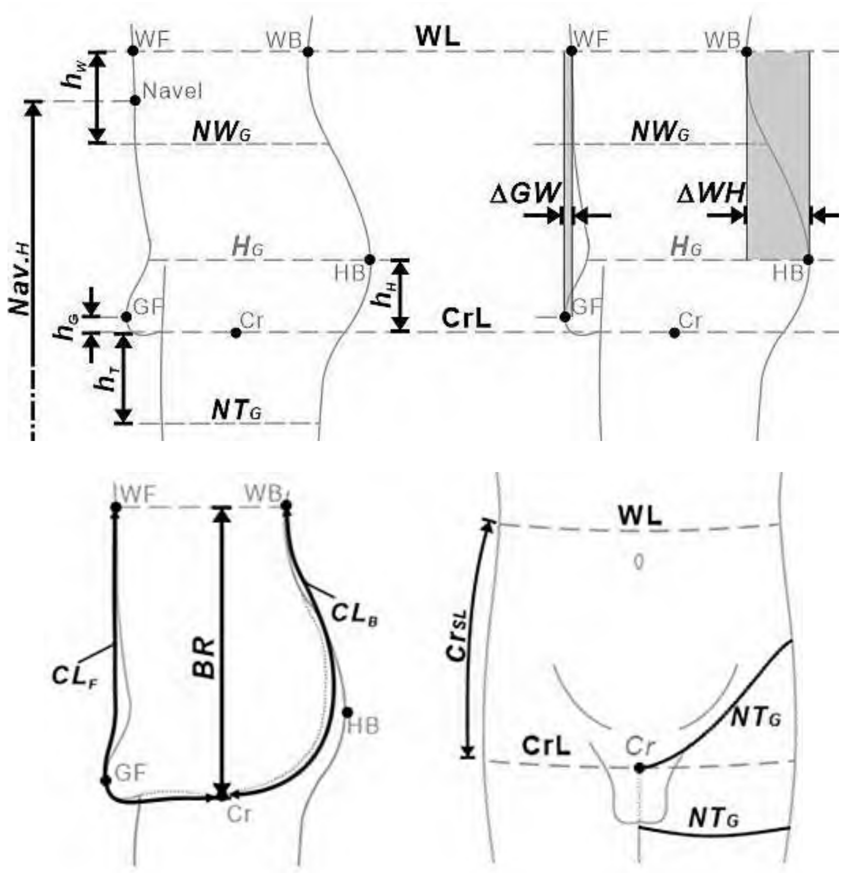
We increased the number of body measurements for improving the pattern making of men’s underwear. All primary and additional body measurements belong to lower torso and can be taken directly from the bodies scanned and shown in Figure 3.14.

As shown in Figure 3.14, *WL* is natural waistline/level as narrowest girth part. *WF*, *WB* are waist front and waist back points. *HL* is hip line across the peak of buttocks, *HB* is the peak of buttocks. *GF* is genitalia peak point. *CrL* is crotch line/level; *Cr* is crotch point.

As shown in Figure 3.14a, 14 primary measurements of the lower torso which have been obtained by the 3D scanner and can be used for underwear design. As shown in Figure 3.14 (a, upper) the schemes of measuring of the curve and lengths which are locating on the body; As shown in Figure 3.14 (a, lower) the primary body measurements divided into three groups - horizontal, vertical, and arc.



a



b

Figure 3.14 – Developing scheme of body measurements: a – primary; b – additional

(1) primary horizontal measurements:

WB_D the distance from concave waist back to back vertical guideline

HB_D the distance from hip peak to back vertical guideline

GF_D the distance from genitalia bulge peak to back vertical guideline

$Abd._D$ the distance from the front abdomen to back vertical guideline

(2) primary vertical measurements

$\Delta(W_H - H_H)$ the vertical distance from natural waist to hip level

H_H the hip height

W_H the natural waist height

(3) primary arc measurements

CL the full crotch length from *WF* through *Cr* to *WB* measuring very close to the body

W_L the length from natural waist to the waistband (on front, side and back) close to the body

H_{SL} the side length from natural waist to a hip level close to the body

T_{SL} the side length from natural waist to thigh level close to the body

As shown in Figure 3.14b, to describe some crucial characteristics of male bodies, we listed 18 additional data which have been calculated after our data processing. As Figure 3.14b showed, the additional measurements have been marked as an abbreviation,

(1) additional horizontal measurements

$\Delta GW = GF_D - Abd._D$ the difference between waist front and genitalia bulge

$\Delta WH = WB_D - HB_D$ the difference between hip peak and waist back

$\Delta(H_G - W_G)$ the difference between hip and natural waist girth

NW_G new waist girth as waistband located below natural waist level

NT_G new thigh girth as underwear bottom in horizontal and slope directions

(2) additional vertical measurements

$Nav._H$ the navel level height

GF_H the height of genitalia peak follows the wearing habits

Cr_H the crotch level height

$BR = W_H - Cr_H$ the distance from natural waist to crotch level

$h_G = GF_H - Cr_H$ the difference between genitalia peak and crotch level

$h_T = Cr_H - T_H$ the difference between crotch and new thigh level, underwear bottom

$h_H = H_H - Cr_H$ the difference between hip and crotch level

$h_W = W_H - NW_H$ the difference between natural waist to waistband level

(3) additional arc length measurements

CL_F the front crotch length, from *WF* front to *Cr* across genitalia peak

CL_B the back crotch length from *Cr* to *WB* through the hip groove

Cr_{SL} side length from waist to crotch, leg inside minus outside length

$\Delta F = CL_F - BR$ the value describing genitalia bulge

$\Delta B = CL_B - BR$ the value describing hip (buttocks) bulge

Among additional measurements, h_G describes the genitalia position which can move upward or downward according to personal wearing habits. ΔF is a quantitative characteristic of the genitalia volume. ΔGW describes the male genitalia bulge in the horizontal direction (small width of the grey rectangle in Figure 3.14 by *GF* and *WF*. It will be negative when the abdomen (waist front) bugles larger than the genitalia bugle. From our statistic, 25% scanned males have negative value of ΔGW (average negative value mean is -0.68 cm), and 75% scanned males are the positive value of ΔGW (average positive value mean is 0.80 cm).

3.3.3. Statistical analysis of new measurements

The five critical measurements NW_G, h_W, h_G, ΔGW, ΔWH, NT_G can be used for underwear design and male bodies classification. We take the NW_G position -8 cm below *WL*, and NT_G position on *Cr* (0°) as an example, the details will be introduced in later chapters.

Firstly, the Cronbach's Alpha (α) is 0.86 through reliability analysis of SPSS, and all data have good scores of reliability test of internal consistency. Then all data at the level of significance 95% are not strongly correlated through bivariate analysis of samples' crucial coefficient of correlation.

Secondly, we have applied the method of correlation analysis to choose key-measurements for underwear design and classification of male bodies. The crucial correlation coefficient $r = 0.321$ for $n = 115$ and the level of probability α = 99.9% (0.001) in according with Bolshev-Smirnov statistical handbook [12, pp.248]. To choose the new additional measurements, we should be sure about it independent from primary measurements. The correlation matrix (Appendix II Table II.1) between additional and primary measurements and the number of strong relationships between them. The results show the common fraction, where *r* is correlation coefficient, *sig.* is p-value the significance of the test, if the p-value is less than the chosen significance level ($\alpha < 0.01$, two-tailed) it suggests that the observed data is sufficiently significant about their correlation. We take $NW_G = -8$ cm below *WL* and NT_G horizontal position as examples.

Appendix II Table II.1 show that four additional measurements such as ΔGW, $\Delta(H_G - W_G)$, Cr_H, $NT_G\,(CrL, 0°)$ are completely independent. These four additional measurements can be combined with any primary measurements to create a new approach to pattern block making.

Several measurements have some significant (strong) correlation with primary measurements because some of them are based on primary measurements optimized and calculated. The rest additional body measurements have strong correlation with primary measurements and need more careful consideration before their combinations. The Appendix II Table II.1 shows that only two measurements such as *ΔF* and *ΔB* have four significant correlations with several primary measurements. For example, the measurement *ΔB* has the significant correlations with *CL*, HB_D, GF_D, $Abd._D$ and the measurement *ΔWH* has the significant correlations with WB_D and HB_D, instead of many measurements we use two mentioned measurements – *ΔB* and *ΔWH* – for bodies' classification and pattern design. The h_H even have four strong correlations, but with insufficient significances. Even the primary measurements can be measured by the body scanner directly, they are still a "new" kind of measurements which can be applied to men's underwear design.

3.3.4. New measurements for waist

Nowadays the waistband of daily underwear excepting some functional kinds of garments is very often located below the natural waist (*6510*) and usually below the navel. So, to design the waistband (*6520*) in any comfortable positions for each body types, we should know the girth of lower natural waist named as new waist girth NW_G.

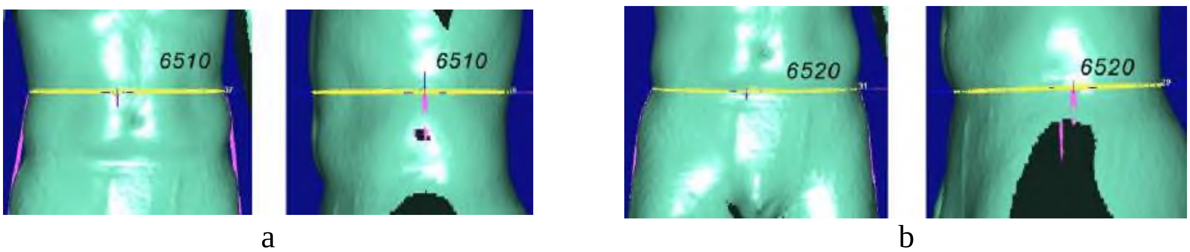


Figure 3.15 – Positions of waist and waistband girth, a – natural waist line, b – waistband line

The "Appendix II Table II.2" shows new additional measurements which were taken in waist area. Through Shapiro-Wilk (*S-W*) test by SPSS, n =115, *sig.* > 0.05, and the effective diagnostic tool of *Q-Q* plot, all the data distributions are close to a linear line, indicating that the data is normal. We chose these four measurements to calculate the waistbands girth and the differences between waist girth and hip girth.

Through the analysis of consumer preferences, the average distance between the waistband girth (NW_G) and the natural waist (W_G) following after individual preferences is approximately 7.7 cm (about 1.7 cm below the navel level, $Nav._H$). This level is located close to the top of anterior and posterior of the superior iliac spine; it is better to put the waistband at this position so that the waist can be supported by both bones, and provide a good fixed effect and pressure receptivity.

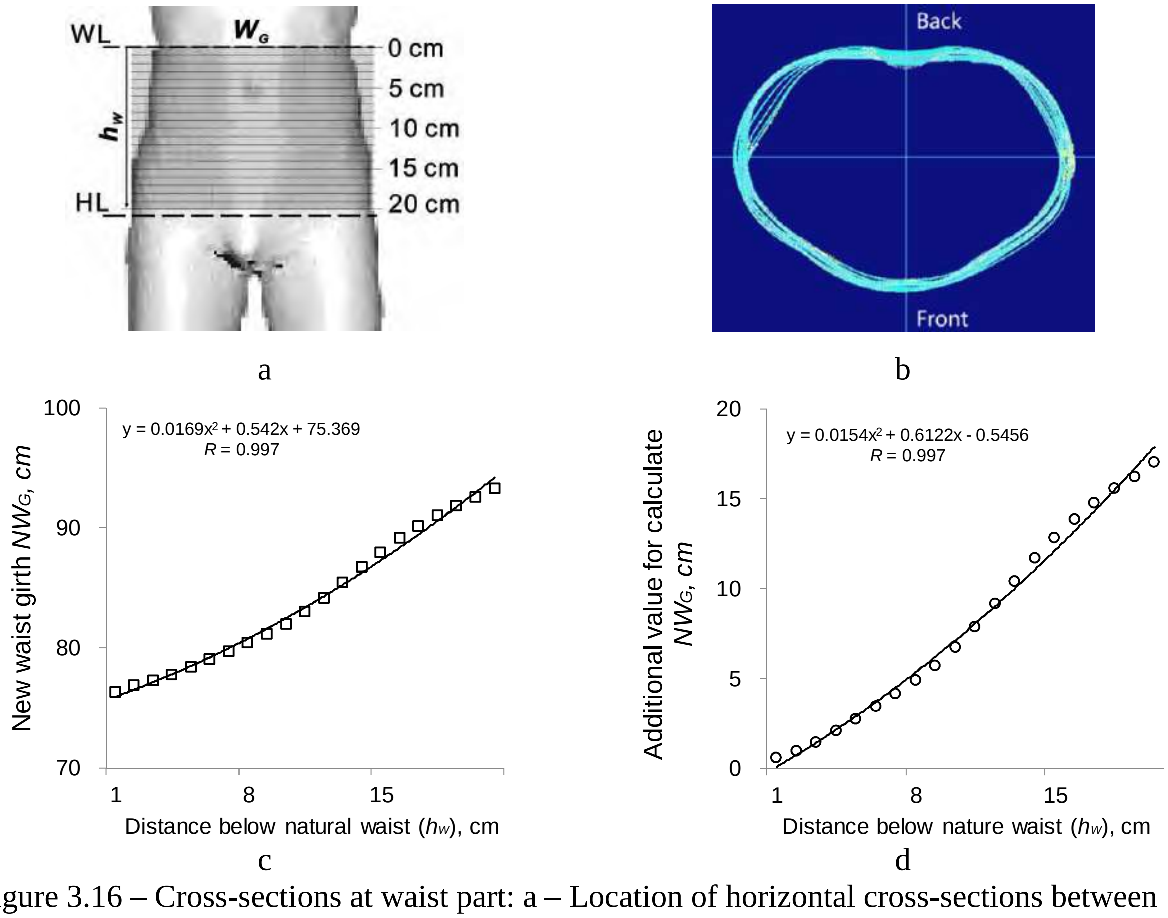


Figure 3.16 – Cross-sections at waist part: a – Location of horizontal cross-sections between W_G and NW_G; b – NW_G cross-sections; c – the diagram of average NW_G depending on h_W; d – the diagram of average NW_G depending on h_W and W_G

We completed the next step. The average distance between the natural waist and the hip level is 21.51 cm, so we chose the distance from WL to lowest NW_G as 20 cm. We named the distance between W_G to NW_G as “h_W”. Then we identified these cross-sections from scanned bodies in 1cm intervals. Figure 3.16 shows the location of cross-sections and the box-plot change.

As Figure 3.16c shown, NW_G is bigger than W_G and all mean values are presented the steady incremental trend. The box of interquartile range (IQR) become gradually smaller when moved to 20 cm (near hip level), the average of standard deviations is ± 6.08 cm. Based on linear trend of mean values, we found the relationships between NW_G and W_G, h_W

$$NW_G = 0.02 \cdot h_W^2 + 0.54 \cdot h_W + 75.37 \quad (2.1)$$

$$NW_G = 0.02 \cdot h_W^2 + 0.61 \cdot h_W - 0.55 + W_G \quad (2.2)$$

where NW_G is new waist girth used for the waistband location, cm; h_W is the decline distance of NW_G from natural waist, cm. The correlation coefficient $R = 0.99$ when the level of probability 95%.

New waist girth as the body measurement for calculating the waistband is significantly higher than the natural waist girth for most of the young male, even somebody with higher body weights. This equation must be more precise to calculate the girth of new waist for design underwear waistband size.

Second, we have measured underwear waistband height, similar to h_W. As shown in Figure 3.17, the height of waistband at front, side and back are different, not in horizontal.

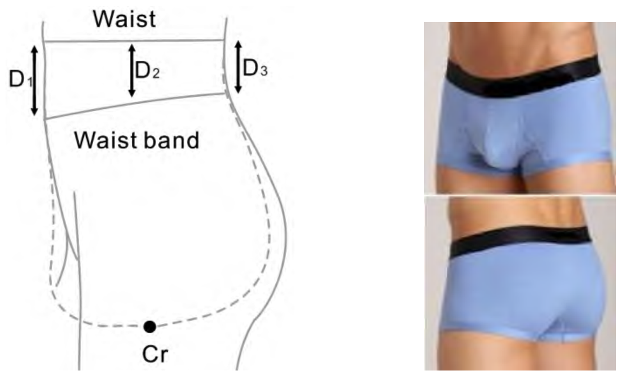


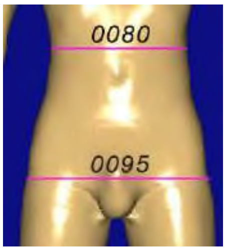
Figure 3.17 – Measurements of distance between waist and waistband

Therefore, we must take attention to this detail of waistband part in pattern block design. By our measurements, the average values D_1 – measure from waist to waistband at the front is during 6.2…13.0 cm, D_2 – during 5.8…10.2 cm, D_3 – during 5.6…8.4cm. h_W include D_1, D_2 and D_3, and is equal to the average value of $(D_1 + D_2 + D_3) / 3$. It was measured from waist level to real underwear waistband at front, side and back positions depends on individual underwear. These results can help us to find more normal position of the waistband in the future design.

From D1, D2 and D3, we can know which belt style men like to wear, mostly lower in front and higher in back. In addition, the average h_W we measured from the belt (new waistline) to the waist circumference is between 6.5...10. 8 cm.

3.3.5. New measurements for front

Depending on male body characteristics in front (genitalia), the consumers will encounter a variety of conditions when they are wearing underwear, such as feelings of different tightness in genitalia area provided by different front pouches of underwear [51].



a

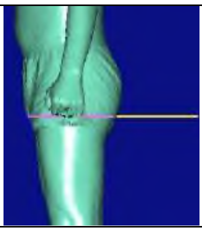
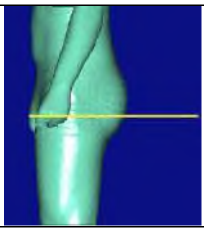
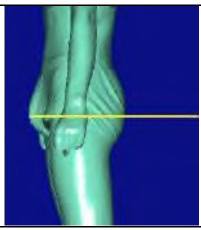
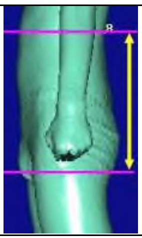
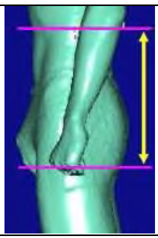
b

Figure 3.18 – Measurements in front

Base on the data of 3D body-scanner, in the front and profile perspective, as shown in Figure 3.18. ***0080*** – Height of natural waist level (vertical distance from waistline to floor); ***0095*** – Height of genitalia level, based on the peak point of front genitalia bulge (vertical distance from peak point to floor); ***0550*** – Distance from the waist front to the back vertical guideline (horizontal distance at waist level); ***0670*** – Distance from the peak point of front genitalia bulge to the back vertical guideline (horizontal distance at peak point level).

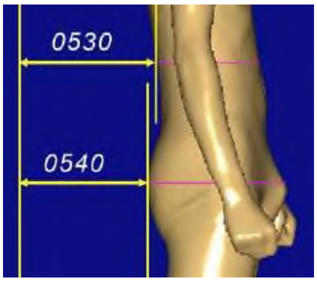
"Appendix II Table II.3" shows the front body measurements taken from profile cross-section. We used them to explore the features of genitalia area, to get a new way to describe front part of classification and structure design. We have analyzed data through *SW* test and *Q-Q* plot by SPSS, n =115, *sig*. > 0.05. "Appendix II Table II.3" shows the statistics and proves that the data distribution is close to the linear line.

Table 3.2 – Body samples for front part

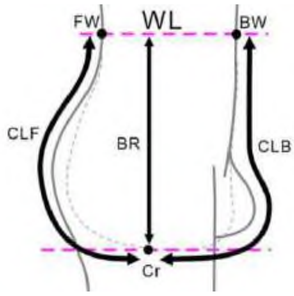
Types	S	M	L
Examples with different ΔGW			
Percentage, %	16.67	71.67	11.67
Examples with different ΔF			
Percentage, %	21.67	68.33	16.67

3.3.6. New measurements for hip

Consumers also feel different perceptions of tightness in the hip area provided by different constructions of underwear (few seams or seamless). Different body characteristics, body movements (squatting) and knitted materials properties will cause the uncomfortable/comfortable feeling and deformation of underwear back.



a



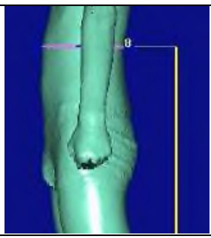
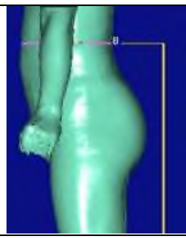
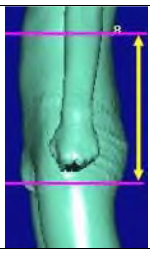
b

Figure 3.19 – Measurements in back

As shown in Figure 3.19, ***0530*** – Distance from the waist back arc to the back vertical guideline (horizontal distance at waist level); ***0540*** – Distance from the peak point of hip back to the back vertical guideline (horizontal distance at hip level).

“Appendix II Table II.4” shows the back measurements taken from profile cross-sections. Through analysis, the test of *SW sig*. > 0.05, the data in Table 2.6 are normal.

Table 3.3 - Body samples for back part

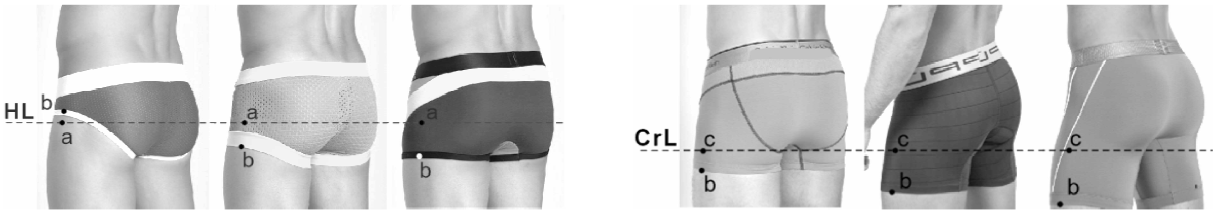
Types	S	M	L
Examples with different ΔWH			
Percentage, %	13.56	69.49	16.95
Examples with different ΔB			
Percentage, %	11.67	73.33	15.00

The additional data ΔB is a quantitative parameter of the bulge prominent of the hip (*HB*) and *WB*. ΔWH is the parameter for describing the hip horizontal bulge; there are no negative values. ΔWH is equal to the value of back (hip) bulge and the position (shape) of the sacrum and fat mass (location) of hip soft tissues.

3.3.7. New measurements for thigh

The underwear bottom has various kinds of positions. Some tilt and another horizontal. So, to design the underwear bottom for thigh, we should know the girth of whole thigh part – new thigh girth NT_G, not only in horizontal.

Figure 3.20 displays six kinds of men's underwear. As we can see, the bottoms have different heights/angles. We marked some important points located on *HL* and *CrL*: point "*a*" on *HL*, "*b*" on underwear bottom, "*c*" on *CrL*.



a b

Figure 3.20 – Two cases of bottom locations: a – higher than *CrL*; b – lower than *CrL*.

Figure 3.20a shows the first case when the underwear bottom is located upper *CrL*. As we can see, this case includes the different locations of point "*b*" (a briefs and trunks), different bottom girth and slope, and different length of side seams. Figure 3.20b shows the second case when the underwear bottom is located below *CrL*. This case with the different locations of point "*b*" represents the various underwear styles of tight-fitting boxers (from short to long).

Figure 3.21 shows the side length front waist to hip and thigh level, and the waistband to hip level.

a b c

Figure 3.21 – Side line: a – waist to buttock height left (*7010*); b – waist to hip/thigh left (*7020*); c – waistband to buttock height left (*7015*)

"Appendix II Table II.5 and Figure II.4" shows the measurements method of the features of thigh line in different cases. Through analysis, the test of *S-W sig*. > 0.05, the data are normal. Moreover, to analyze the first case bottom position, we need to measure thigh girth in an oblique direction, we found the oblique thigh cross-sections from the scanned bodies. Figure 3.22a shows how we cut the thigh by several oblique (per 5°) sections from 0…60°.

The vertex of the cut angles is located at the inner thigh and close to crotch level as possible. When the angle is bigger than 60°, it mostly make the sloping side of underwear upper than the iliac crest and near to the *WL*, so we take 60° as the maximum angle. However, each angle from 0…60° has the crossover points with body contour (see Figure 3.22a). Thus we can measure the side length (*SL*) from *WL* to each crossover points of back contour.

Figure 3.22a shows the bottom lines for the second case when the bottoms are lower than *CrL*. For this underwear, the bottom needs the horizontal position. So, we declined cross-sections per 1 cm from 0 to 10 cm (named this distance as "h_T") along the thigh. Figure 3.22b shows the relationship between the cutting angle and NT_G, and average values of NT_G gradually increasing. Figure 3.22c shows the side length measured from natural waist level down to *CrL*. To make the underwear bottom highly close to thigh according to different tensile and recovery properties of knitted materials, we need add a negative increment value (ease) to NT_G.

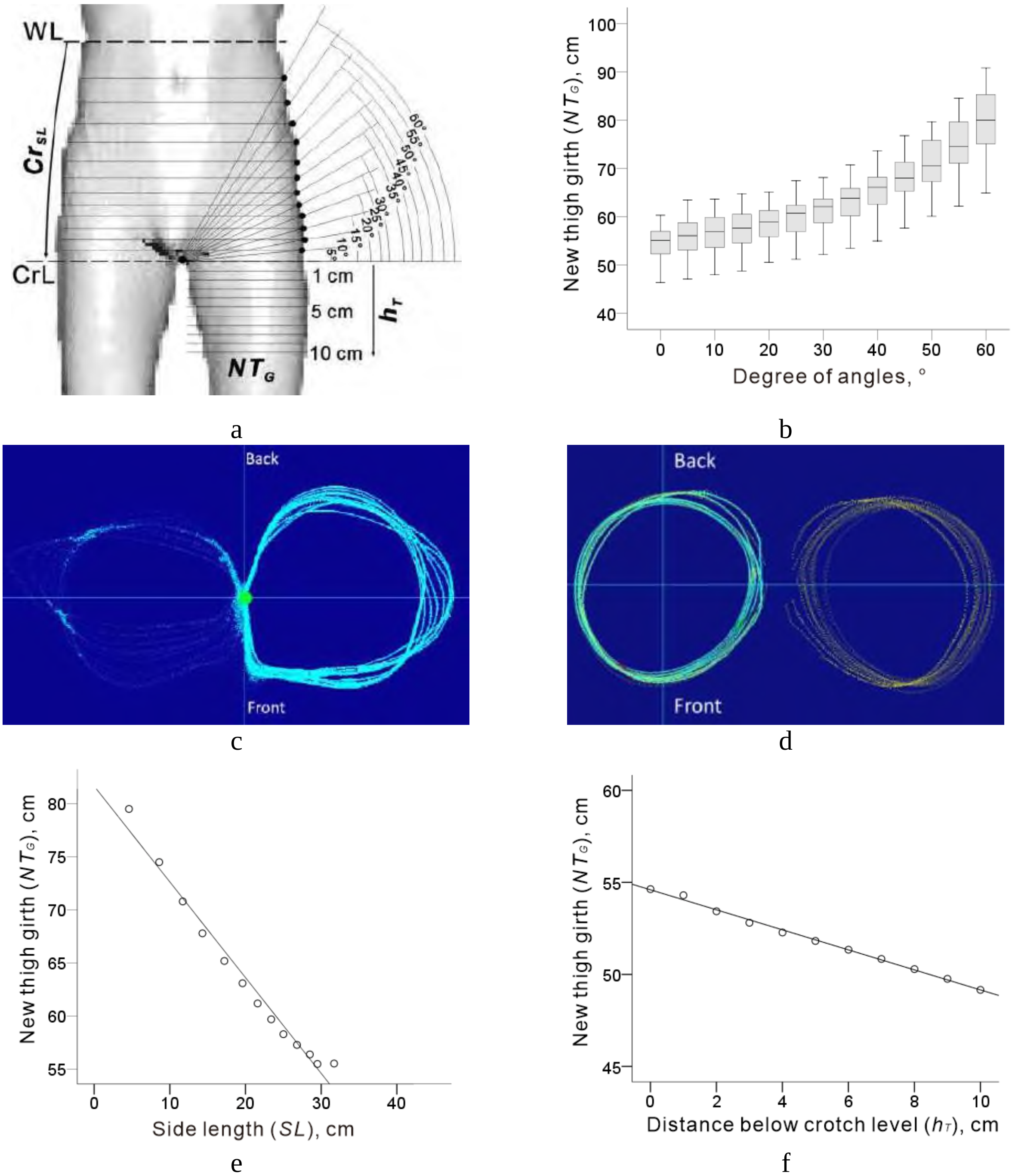


Figure 3.22 – Analysis of new thigh: a – thigh cutting in different angle; b – thigh cutting in horizontal; c – diagram of side length and NT_G; d – diagram of h_T and NT_G

The linear relation between *SL* and NT_G is significantly negative; the correlation coefficient is -0.989, *Sig.* is 0.000. Figure 3.22d shows the relation between horizontal cross-sections girth NT_G and h_T. Correlation coefficient is -0.998 and *Sig.* is 0.000, the linearity relation is significantly negative with high adequacy. We found the one-variable linear equations for calculating new tight oblique girth and horizontal girth NT_G.

$$NT_G = 81.64 - 0.89 \cdot SL \qquad R = -0.989 \qquad (2.3)$$

$$NT_G = 54.59 - 0.54 \cdot h_T \qquad R = -0.998 \qquad (2.4)$$

where NT_G is new thigh girth measured below or upper natural thigh level, cm; SL is side seam length measured from natural waist, cm; h_T is a range of NT_G below CrL; R is correlation coefficient for the level of probability 95%.

Figure 3.23 shows the distance between the inner thighs, it is the distance mentioned in Figure3.1b.

$$\Delta_{WB} = |(D_{FL} - D_{SL}) \cdot [(16 - h_W) / 16]| \qquad (2.5)$$

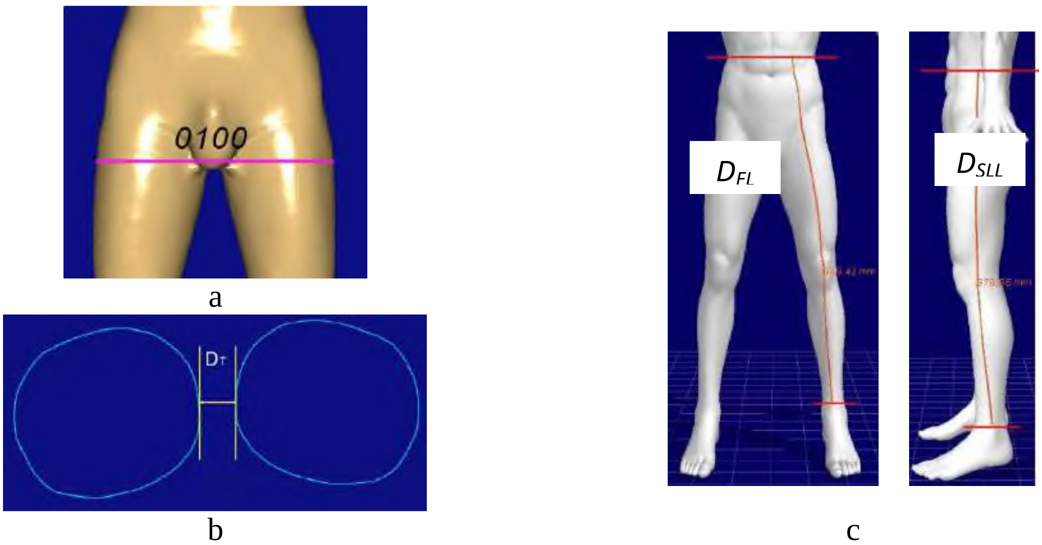


Figure 3.23 – Measurements on male thigh: a – cross-sections of the taken at crotch level; b – distance between thigh left and right at crotch level; c – measurements of the D_{FL}, D_{SL}

We cut these thigh cross-sections at crotch level. The average distance between thigh left and right at crotch level is 2.38 ± 0.51 cm, the range is 1.5...3.9 cm. Moreover, D_{FL} is the length from waist to ankle front, D_{SL} is the length from waist to ankle side, and these two values are to calculate the balance value Δ_{WB} at waistband front and side by equation (2.5), which is equal the difference between front and side height measured from nature waistline to the ankle.

3.4 New classification

The *first level* is based on W_G and H_G and visually defines the total sizes of lower torso (small or large for slim or obesity bodies), mark * in the extra-large WG as an option for overweight men. The second level includes key measurements that describe the physical male characteristics. The fourth and sixth stages of mark * are options for further elaboration of this classification and can also be used for drafting and more detailed classification. Therefore, the classification of male lower body is divided into the first, second, third and fifth stages.

The torsos of the *first stage* of the *first level*, because the range of H_G is 82.80…114.10 cm, mean is 94.24 cm, quartiles are Q_1 = 91.65 cm, Q_2 = 94.10 cm, Q_3 = 97.75 cm, the standard deviation is 5.50 cm tested by SPSS frequencies, three intervals have been divided based on the value of quartiles, so the interval for classifying middle type of male bodies is 92…98 cm, middle type “*M*” for underwear production is 94 cm.

The $\Delta(H_G - W_G)$ range of the *second stage* is 17.80...26.0 cm, the quartiles are Q_1 = 14.35 cm, Q_2 = 17.65 cm, Q_3 = 20.80 cm, the interval for middle type of male body is 14…21 cm, middle type “*M*” for underwear production is 18 cm.

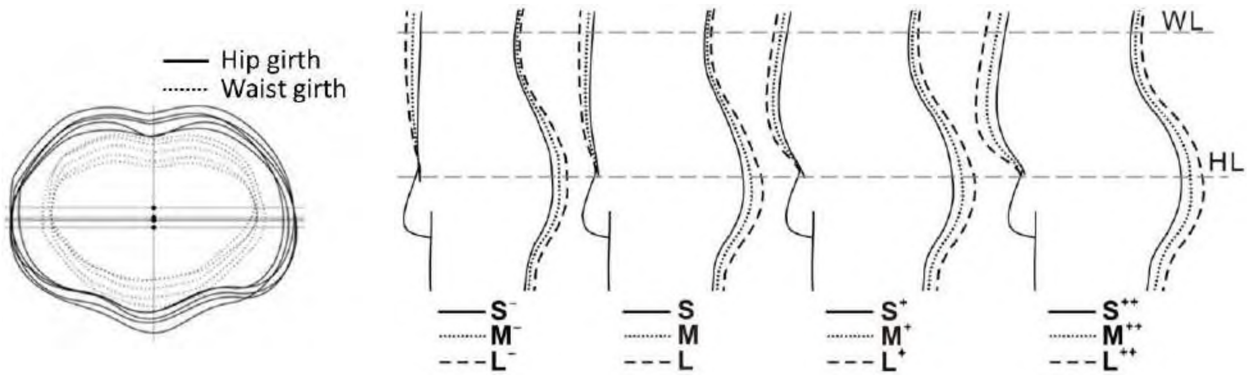
The range of ΔF of the *third stage* of the *second level* is 5.70…13.60 cm, the quartiles are Q_1 = 8.30 cm, Q_2 = 9.50 cm, Q_3 = 10.70 cm, the interval for middle type of male body is 8.3…10.7 cm, middle type “*M*” for underwear production is 9.5 cm.

The ΔGW range of the *fourth stage* is -2.90…2.80 cm; the quartiles are Q_1 = 0.00 cm, Q_2 = 0.50 cm, Q_3 = 1.10 cm, the interval for male middle type is 0.0…1.1 cm, but this front part also comply with the design, so the small type of “*S*” underwear production we recommend is 0…0.5, middle type “*M*” is 0.5…1.5 cm, large type “*L*” is > 1.5, and when *ΔGW* become (larger, the front pouch will be larger, and the appearance will be similar to a pocket. The daily underwear are usually less than 3 cm, and give comfortable pressure to genitalia, not slack in front.

The *ΔB* range of the *fifth stage* is 3.60…14.50 cm; the quartiles are Q_1 = 6.40 cm, Q_2 = 7.50 cm, Q_3 = 8.60 cm, the interval for middle type of male body is 6.4…8.6 cm, middle type “*M*” for underwear production is 7.5 cm.

The *ΔWH* range of the *sixth stage* is 1.10…8.80 cm; the quartiles are Q_1 = 2.70 cm, Q_2 = 4.10 cm, Q_3 = 4.85 cm. The torsos of middle type “*M*” with 2.7…4.9 cm need the size of underwear 4.1 cm.

Table 3.4 shows the new types of male bodies of two levels. Figure 3.24a shows the overlapping cross-sections of H_G and W_G for the scanned males with the similar waist and hip girth. The “Appendix II Table II.6” shows the new classified bodies samples.



a b

Figure 3.24 – Lower torso: a – Cross-sections of H_G and W_G; b – profile views

We can see the big differences between the configurations of the waist and hip cross-sections, on one hand, and the proportion between the front and the back, on the other hand (namely more soft tissues at abdomen or at hips etc.). The variety of proportions between H_G and W_G will reflect the lower torso contour. We chose $\Delta(H_G - W_G)$ as the *second stage* of the *first level.*

To make classification, we should know some measurements such as W_G, H_G, GF_D, and WB_D *etc*. in Figure 3.14a, then *BR*, ΔF, ΔGW, *etc*. in Figure 3.14b.

For example, if the body has a small H_G and $\Delta(H_G - W_G) > 21$cm, it can be marked as "$\boldsymbol{S^{-}}$". If the body has middle H_G and $\Delta(H_G - W_G)$ in the range of 14…21 cm, it can be marked "***M***". For a large H_G but close to W_G (the difference is 0…14 cm) or W_G larger than H_G (< 0), the body will mark as "$\boldsymbol{L^{+}}$" or "$\boldsymbol{L^{++}}$".

The first level has two stages. To identify the *first stage*, we need to measure H_G and W_G. Based on the value of H_G, we can put the body to ***S***, ***M***, ***L*** types in according with the intervals established: smaller than 92 cm, between 92…98 cm, and bigger than 98 cm. After calculating the difference $\Delta(H_G - W_G)$, we describe the contour by marks "++" for the extra large W_G; "+" for large W_G (or similar values of H_G and W_G); *"blank mark"* for median of W_G (called normal W_G); "–" for the extra small W_G.

The second level characterizes the morphology of male lower torso and includes indexes of the front and the back. It should be noted that *second level* must be processed with four values. *The second level* has *4 stages*. ΔF defines the sizes of male genitalia and lower abdomen (with much fat or not), and ΔB defines the sizes of hip, then combine them with ΔGW (only to give details about difference between male genitalia and waist front bulge) and ΔWH (only to give details about difference between buttocks bulge and waist back concave), the front and the back as ***S***, ***M***, ***L*** can be presented.

Third stage and *fourth stage* are related to the body front and needs ΔF and ΔGW to identify the types of ***S***, ***M***, and ***L***. If the body has $\Delta GW = -0.1$ cm and $\Delta F = 7.5$ cm, we can mark it as ***S***.

The *fifth stage* and the *sixth stage* are related to the buttock shape, and ΔB and ΔWH are used to choose ***S***, ***M***, ***L*** types. There is a special case when four body measurements from *third*, *fourth fifth* and *sixth stages* cannot match same intervals completely. E.g., ΔF (or ΔB) in ***S*** types, ΔGW (or ΔWH) in ***M*** types, we comply with the principle of ΔF (or ΔB) priority to define ΔGW (or ΔWH) to ***S***.

Finally, we mark the lower torso and underwear such as ***M¯/LM*** and so on. It is east to recognize the details of type identification. "***M¯***" describe the total type of body based on W_G and H_G, "***LM***" describe the front (ΔF, ΔGW) and hip (ΔB, ΔWH) characteristics. In totally, there are 108 new lower torso types (classifications) o by our statistics $108 = C_{12}^{1} \cdot C_{3}^{1} \cdot C_{3}^{1}$.

Table 3.4 – New classification of male lower torso

<table>
<tr><th rowspan="2">Main type</th><th rowspan="2">Subtypes algorithms</th><th colspan="4">Intervals, cm</th><th rowspan="2">S.D., ±</th></tr>
<tr><th>S (small)</th><th>M (middle)</th><th colspan="2">L (large)</th></tr>
<tr><td rowspan="2">First level</td><td>First stage, H_G</td><td>< 92</td><td>92 … 98</td><td colspan="2">> 98</td><td>5.5</td></tr>
<tr><td>Second stage, $\Delta(H_G - W_G)$</td><td>> 21, Mark “–” (small W_G)</td><td>14…21, “Blank mark” (middle W_G)</td><td>0…14, Mark “+” (large W_G)</td><td>* < 0, Mark “++” (extra large W_G)</td><td>4.3</td></tr>
<tr><td rowspan="4">Second level</td><td>Third stage, $\Delta F = CL_F - BR$</td><td>< 8.3</td><td>8.3...10.7</td><td colspan="2">> 10.7</td><td>1.5</td></tr>
<tr><td>* Fourth sub-stage, $\Delta GW = GF_D - Abd._D$</td><td>< 0</td><td>0...1.1</td><td colspan="2">> 1.1</td><td>0.7</td></tr>
<tr><td>Fifth stage, $\Delta B = CL_B - BR$</td><td>< 6.4</td><td>6.4...8.6</td><td colspan="2">> 8.6</td><td>1.5</td></tr>
<tr><td>* Sixth sub-stage, $\Delta WH = WB_D - HB_D$</td><td>< 2.7</td><td>2.7...4.9</td><td colspan="2">> 4.9</td><td>1.5</td></tr>
<tr><td colspan="2">Proportions rates, %</td><td>12…20</td><td>64…73</td><td colspan="2">11…17</td><td>-</td></tr>
</table>

The mark “++” extra large and the sub-stages of fourth and sixth are further expounded on this classification.

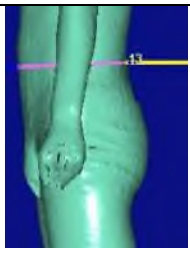
3.5. The use of new measurement signs for designing underwear

We drew the basic block based on W_G and additional measurements for personal customisation and mass manufacture. For the typical person, it is simpler to just measure the body sizes. For the mass manufacture, we describe briefly the calculation and application of new method. The example of our new pattern block t with new important measurements, the details is shown in chapter 5. Previously we selected the reasonable eases of knitted material according to the new classification.

We draw a vertical guideline according to *BR* value (median is 31.4 cm for middle type), define NW_G for waistband (*/4-6/*) and H_G level (*/2-3/*) using h_W and h_H. We calculate 0.25 H_G and 0.25 NW_G for the front and the back width. Then, we draw the ΔWH (median is 4.1 ± 1.5 cm) along the extension of *CrL* in the back and in front piece to make sure that point *24* has the coordinates h_G and ΔGW.

The bottom line is usually limited by side seam and inseam line, it will change from small to large size by NW_G, H_G, ΔWH *etc.* Moreover, under the easy deformation of underwear bottom, the length of the bottom in the pattern should be shorter (negative ease value) than the real measurement to keep a good tight-fitting. In this new pattern block, all structural lines depended on the traditional and new body measurements, and all details after scientific experiments have theoretical support. This is an important distinction from other underwear drawings.

Table 3.5 – Examples of male body, cm

Body No. 1	*Body No. 2*	*Body No. 3*
S^+/SS	**M^-/MM**	**L/LL**
		
H:179.3 ΔF: 6.5 H_G: 88.7 ΔGW: -0.1 $\Delta(H_G - W_G)$: 10.7 ΔB: 5.9 ΔWH: 2.0	*H:186.5* ΔF: 10.6 H_G:94.1 ΔGW: 1.7 $\Delta(H_G - W_G)$: 21.2 ΔB: 6.4 ΔWH: 5.6	*H:183.2* ΔF: 10.8 H_G: 110.9 ΔGW: 0.5 $\Delta(H_G - W_G)$: 20.5 ΔB: 9.4 ΔWH: 6.0

As we can see from Table 3.5, the male genitalia bugle (ΔF) increase from *No.1*, *No3* to *No.2*; even *No.1* (S^+/*SS*) and *No.2* (M^-/*LM*) have a lean of profile image but have the significant difference in male genitalia bugle, and *No.1* abdomen bulge similar as *No.3*. E.g., the male body *No.2* (M^{-}/LM) with the measurements shown has a middle size H_G and small size W_G, normal male genitalia size ΔF (8.3...10.7 cm, but bulge size ΔGW >1.1 cm) and middle of buttocks size (6.4...8.6 cm, and bulge size > 4.9 cm).

Summary of chapter 3

1. A scheme has been developed for calculating the position of a point in the crotch area taking into account the morphology of male bodies, the knowledge of which made it possible to introduce new dimensional features for a more detailed description of the front and back.

2. New dimension features have been proposed for parametrization of the lower part of the torsos of male bodies, taking into account their use for underwear structure drawing with different functions. For the first time, the parametrization of the middle of the left and right sides of the torso in the crotch area was performed using the example of Chinese and Russian men, which made it possible to exclude sensory contact to determine the morphological features of this intimate zone.

3. A new classification of the lower part of the torso of male bodies has been developed on the basis of a combination of traditional and new dimensional features with the possibility of use in mass and individual productions. Equations are derived for calculating new dimensional features for conditionally-type bodies.

4. Recommendations on the design of underwear, the choice of its most important areas with more reasonable and satisfactory morphological characteristics. The new database should help create more detailed labeling of men's underwear in order to make consumer choice more simple and clear.

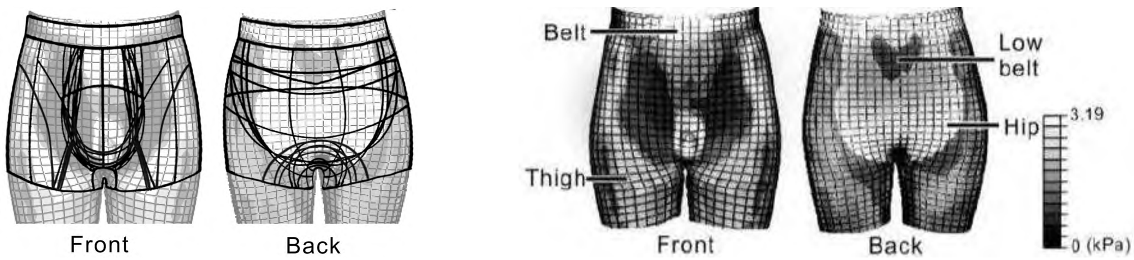
Chapter 4. STUDY OF THE INDICATORS OF MECHANICAL PROPERTIES AND COMPRESSION ABILITY OF KNITTED MATERIALS

Some physical and psychological factors affect the comfort of clothing pressure, so clothing pressure comfort research methods can be divided into subjective and objective evaluation [41]. Because the tight-fitting clothing rely on the material stretch to cling to the human body surface and produce large surface contact pressure. And there are many kinds of men's underwear, even under the same underwear size, due to different functional types, knitted material types and body shapes [217], they will produce different shapes and tightness after wearing, the pressure on the human body is also different. In the study of men's underwear, it is inevitable to study comfort [172]. The existence of clothing pressure has a variety of physiological and psychological impact on the human body, clothing pressure has become an important content in clothing, ergonomics, hygiene [238].

This research focused on the Asian body types. Because the sensitiveness of soft tissues of Asian, European and African people for compression feeling may be different. Previous scientists and experts have already explored the comfort of underwear and tight-fitting clothes in static poses. Some scientists have studied pressure in systems "body-underwear" and tight-fitting stockings, and they have determined the uncomfortable limits (Appendix 1, Table 1.6).

According to the results and analysis of modern men's underwear which are achievable in China, Russia, and world market, various structures we have drawn up from reference books, with the details of functional characteristic and distribution of the reasonable compression pressure on the soft tissue. Figure 4.1 shows the variations of structure lines of Boxers (this type of underwear is quite famous for daily wear and sports) and the reasonable compression pressure range (0…3.19 kPa). Our independent studies have confirmed the compression pressure distribution. Figure 4.1 a shows the overlapped structure lines are used to design different functions; Figure 4.1, b shows the redraw image with the comfortable pressure distribution in lower torso from the underwear (tight-fitting pants) references.

The front insert may provide a better push-up effect, as for sports, shaping when width and length are smaller. Outside seams can be located anywhere as your design, the lines directions can provide the different match with the body dynamic shapes.



a b

Figure 4.1 – The compression pressure in the system "body – underwear": a – variants of shapes and structure lines; b – the front and back pressure

This measurement part is divided into three stages: the first stage is soft mannequin experiment, which makes preliminary preparation and feasibility test for the later human body experiments. The second stage experiment is the body pressure test, the purpose is to establish a new material and underwear pressure objective evaluation standard system and change the old subjective evaluation method. Finally, combine the theoretical model (parametric point of view) with practical applications, to design and verify the feasibility of this theory to reduce production costs and enhance the efficiency of underwear comfort evaluation.

4.1. Instruments and methods of research

4.1.1. Materials for experiments

We investigated 10 knitted materials supplied by I'd company (China) for the Chinese men's underwear market as common knitted materials in terms of fiber and threads component and weaving structure. The other 8 knitted materials were supplied by the Russian market.

According to the preliminary observations, we divided all knitted materials into several groups in accordance with their instrumental and handle properties:

1) Thickness. Five knitted materials were relatively thick (the thickness is 0.9…1.2 mm); ten materials are thin (the thickness is 0.4…0.8 mm).

2) Handle feeling: seven knitted materials were light and soft; nine ones were very elastic and smooth; three ones were relatively less elastic and rough due to the weaving structure.

3) Weight. Figure 4.3 presents the distribution of materials in accordance with its weight. As we can see, the biggest group has included twelve with 160...200 g/cm^2.

4) Structure. The structure of knitted materials: weft knit – single and double sides of plain knit (jersey), single and double sides of rib knit; warp knit – interlock knit, pique knit.

Figure 4.2 shows the surface of several materials in smooth and wrinkled positions which have presented its ability to shape.

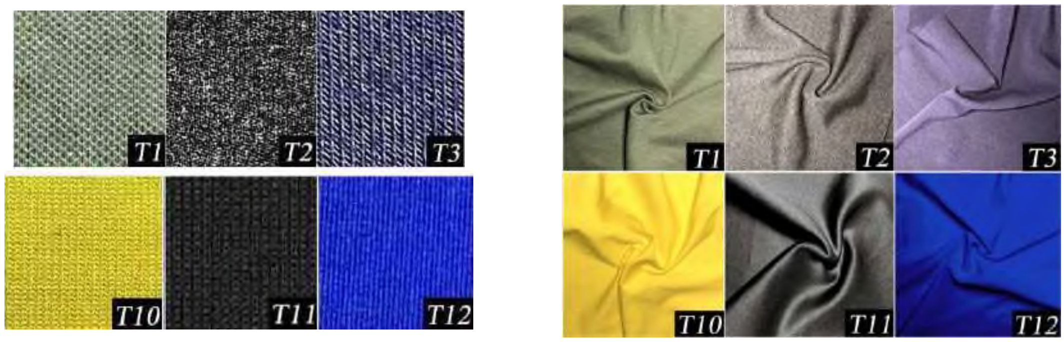


Figure 4.2 – Sample images of knitted material (twice enlarge and sharpening)

As shown in Figure 4.4, most knitted materials are made of Lenzing Modal (yarn count 50…80s, high value indicates yarns light weight and thin), Viscose and combed cotton (yarn count 40…80s), and mixed with spandex (denier 20d).

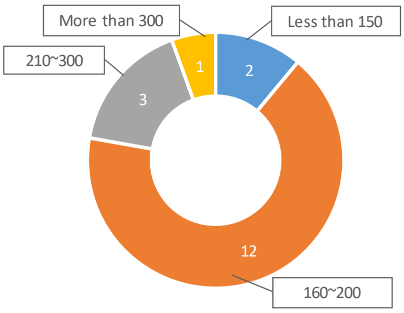


Figure 4.3 – Knitted material weight, g/cm^2

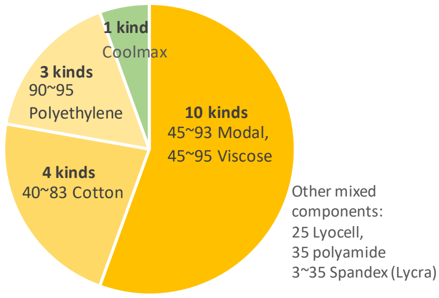


Figure 4.4 – Knitted materials components, %

We chose the United States Tekscan® FlexiForce® A201 sensor with good flexibility and high accuracy. The instrument can measure pressure, through connecting with a recording computer system with eight sensors (Figure 4.5). The length is 197 mm, the thickness is 0.20 mm, the sensor sensing range diameter is 9.53 mm, the acquisition sensing area is 70 mm^2, the pressure acquisition range is 0...4.4 N, measurement error is less than 3%. The A201 has a paper-thin structure. We have adjusted this sensor by different weights to make it suitable to measure human body soft part with knitted material for ensuring accuracy.

a b c

Figure 4.5 – Pressure experiment instrument: a – measurement process, b – pressure sensor, c – Interface of data acquisition system

The pressure acquisition system is LabWindows™/CVI™ analysis system software from National Instruments®. Virtual systems based on Lav Windows™ / CVI™ design play an essential role in NDT, power meter systems, temperature control systems, process control systems, diagnostics and medical applications [107]. The system of this equipment has been improved to design for pressure data acquisition, transmission, display, and recording.

4.1.2. Methods and means of research

To verify the limitary pressure values, we used the objective and subjective methods to do experiment, the sensitivity of compression pressure to the soft tissues has been measured at the following six positions: upper arm (biceps), lower arm (forearm), nature waist, lower waist (waistband), thigh (crotch level), and calf. These selected parts belong to the coverage areas of different underwear (leggings, T-shirts, boxers *etc*.).

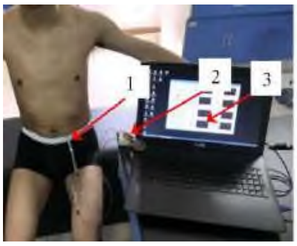
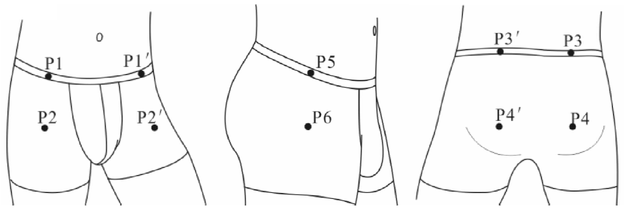
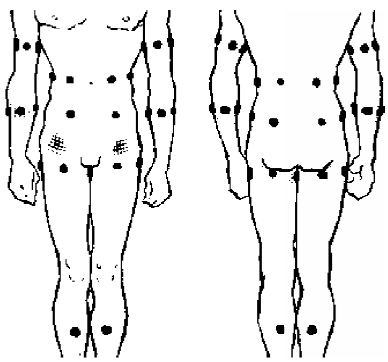


Figure 4.6 – Pressure test on the body (1 – pressure sensor, 2 – measure instrument, 3 – acquisition system,

We set the measuring frequency ten times/sec, and measured the pressure in each position during 30 sec. Before the test, we checked the system of pressure sensitivity and the test range on the computer to better match with the experiment [183]. In our experiment, the initial width of the rectangular samples was 5 cm, the length follows each body girth and has the marked scales on both ends of the sample. We chose14 kinds of men's underwear knitted materials $T_1 \dots T_{14}$ with different stretching ability (Appendix III, Table III.1 and III.2).

We named the sample as "shell". In the experiment, firstly, the pressure test measured simultaneously at two symmetrical points by the sensors, each sensor was put between two layers of artificial leather with three times measurements.

Table 4.1 - Positions of pressure test

<table>
<tr><td colspan="3">Mannequin test points (test No.1)</td></tr>
<tr><td colspan="3">
</td></tr>
<tr><td>Explanation</td><td>Positions</td><td>Points</td></tr>
<tr><td rowspan="2">P1 1/2 right front waistband; P1′ 1/2 left front waistband; P2 Middle point on right front thigh on HL; P2′ Middle point on left front thigh on HL; P3 1/2 right back waistband; P3′ 1/2 left back waistband; P4 Right hip peak; P4′ Left hip peak; P5 Right waistband side; P5′ Left waistband side; P6 Right side on HL; P6′ Left side on HL</td><td>Waistband</td><td>Front, back 4 and side 2 points</td></tr>
<tr><td>Hip level</td><td>Front thighs 2 and hip peaks 2 points; Sides 2 points</td></tr>
<tr><td colspan="3">Body (test No.2)</td></tr>
<tr><td>Image</td><td>Positions</td><td>Points</td></tr>
<tr><td rowspan="6"></td><td>Upper arm</td><td>Front, back and side 6 points</td></tr>
<tr><td>Forearm</td><td>Front, back and side 6 points</td></tr>
<tr><td>Natural waist level</td><td>Front, back 4 and side 2 points</td></tr>
<tr><td>Waistband</td><td>Front, back 4 and side 2 points</td></tr>
<tr><td>Thigh level</td><td>Front, back 2 and side 2 points</td></tr>
<tr><td>Calf</td><td>Front, back 2 and side 2 points</td></tr>
</table>

Secondly, we put the shell on the test position, then changed the ease following the scale and stretched shell in warp and weft direction respectively (in our article we used warp for lengthwise and weft for the widthwise direction of knitted material). Thirdly, we measured the pressure values under the continuous stretching shell, until obtaining the uncomfortable condition from the test on the soft tissue of the body. In other words, the individual sensitivity of expert has been evaluated under the short-term maximum pressure acting and written by the scale: comfortable-uncomfortable. To decrease the error of the measurements, we analyzed the average values and the deviation of the pressure, because during the measurement of the artery and the heartbeat of the body, some errors can appear.

Firstly, we tested on the soft mannequin, and next tested on a real body. 15 males between 18 and 28 years old were measured. All test points are showed in Table 4.1. We combine ergonomic and structural characteristics to determine the following test points.

4.2. Test on soft mannequin

4.2.1. Testing of knitted material pressure in horizontal

We use knitted material “shell” to test at the waistband, the length of the shell is 78.4cm (girth of waist at waistband) for the mannequin and we wrapped it around below navel 4cm. Due to reducing the measurement error when the elongation change on one side, while measuring the other side pressure value. We stretched the material from 0 to 40% for the experiment (because when the elongation reach to 45% the deformation greatly). Tested pressure values at different elongation of points P1, P1', P3, P3', P5, P5', and made linear graphs according to the measurement results as shown in Figure 4.7 a. The pressure value of points P5, P5' at side waistband are higher than the other points in front and back, which is related to the iliac bone part. When elongation is larger than 35% (waistband length is larger than 51.0 cm, and the waistband shrink are not counted), the pressure of P1, P1', P5, P5' exceeds 3.192 kPa, beyond the pressure comfort range. P3, P3' reach to uncomfortable pressure range when elongation are larger than 30% (waistband length larger than 54.9 cm).

Figure 4.7 shows that points P2, P2' have the lowest average pressure. It’s hard to measure the pressure data when the elongations are less than 5%.

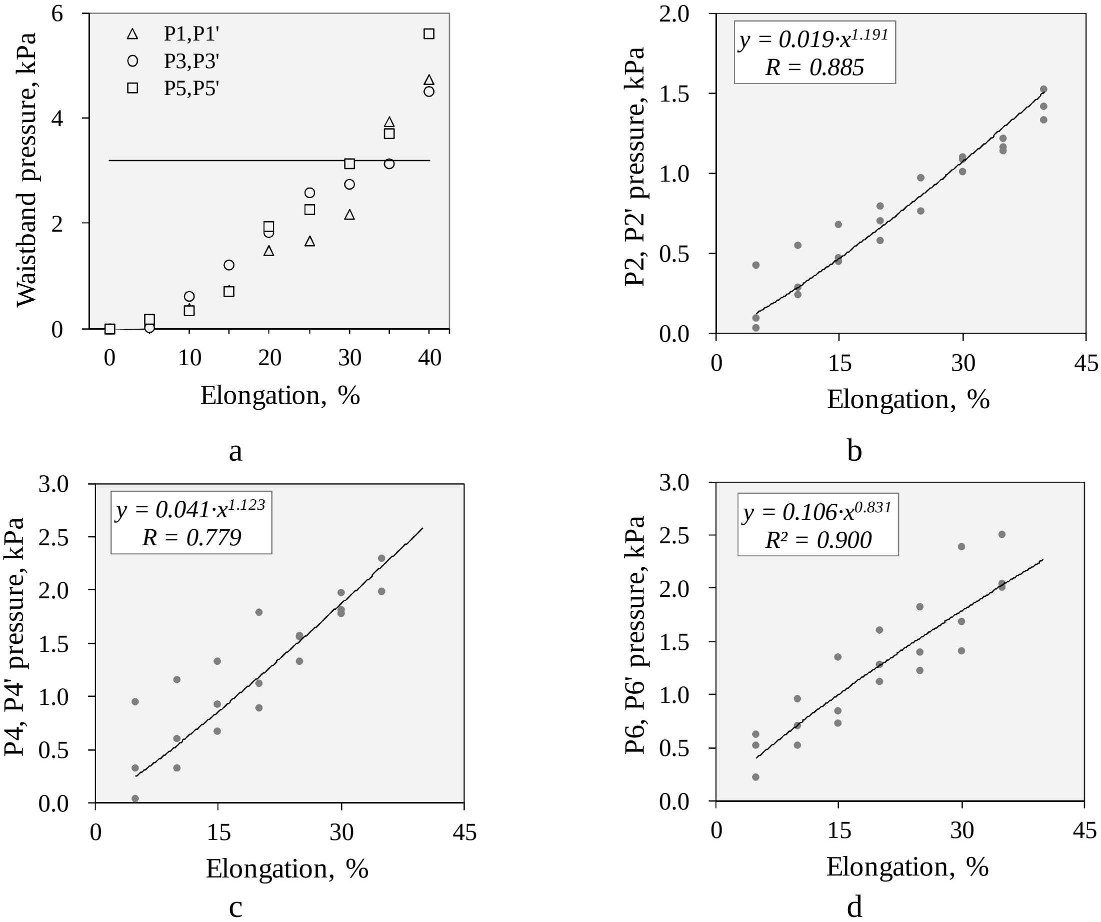


Figure 4.7 – Relation between ease and pressure: a – on waist; b – P2 point; c – on P4 point; d – on P6 point

We can see from test data that the average pressure at the waistband points P (1, 3, 5) are 1.98 kPa. The maximum pressure is 3.70 kPa at elongation 35%. The average points P (2, 4, 6) is 1.09 kPa, the maximum pressure value is 2.50 kPa (at elongation 40%).

4.2.2. Simulate the push-up effect on the mannequin

In the male front part soft tissues (genitals) lifting test, to simulate front push-up effect proved by underwear material's elasticity. We use knitted material and the fake genitals were made from plastic pellets and put on front part of soft male mannequin for the test. The width of material samples are 10 cm (sewing together by two 5 cm pieces), the stretch range also changes per 5% from 0 to

40%, and at the same time record the lifting distance values based on the scale.

As shown in Figure 4.8, a, the maximal push-up effect of the front part is about 2.8 to 4.5 cm, and the average is about 3.4 cm. Due to the particularity of this part, the pressure value is not measured, only the relationship between the lifting distance and the elongation of the material elongation is obtained. The ratio of the elongation and the lift value is positive proportional.

As for the hip lifting experiment. The width of the experimental material is 10 cm, and the length is from the underwear waistband to the bottom (thigh back). To give buttocks “soft tissue” a lifting effect when stretching the material vertically. The predicted test interval is 0…2.0 cm, we recorded the pressure values for each 0.25cm increased, and the test peaks were P4 and P4’. As shown in Figure 4.8 c, d, when we push up the buttocks to 1.75…2.00 cm, the pressure values of the three materials reached 3.86…4.30 kPa, exceeding the comfort threshold of 3.19 kPa. Therefore, we assume the maximum lifting distance (and with comfortable pressure) of material on the male hip is about 0 to 1.75 cm.

A preliminary reasonable elongation range was obtained by performing an elongation change pressure test on the human body model. The stretched size of the knitted fabric of the underwear is increased, and the proportion of the pressure increase is constant; the greater the pressure value, the higher the elongation of the knitted fabric.

Based on comfortable pressure range (1972, M.J. Denton, [38]), the maximum elongation (negative ease) on waist part should be less than the 31.7%; hip should be less than 38.3% but must take into account the maximum elongated size (elongation) of different materials. To make the underwear on the body produce reasonable and comfortable pressure feeling, ease value may be more than -10%.

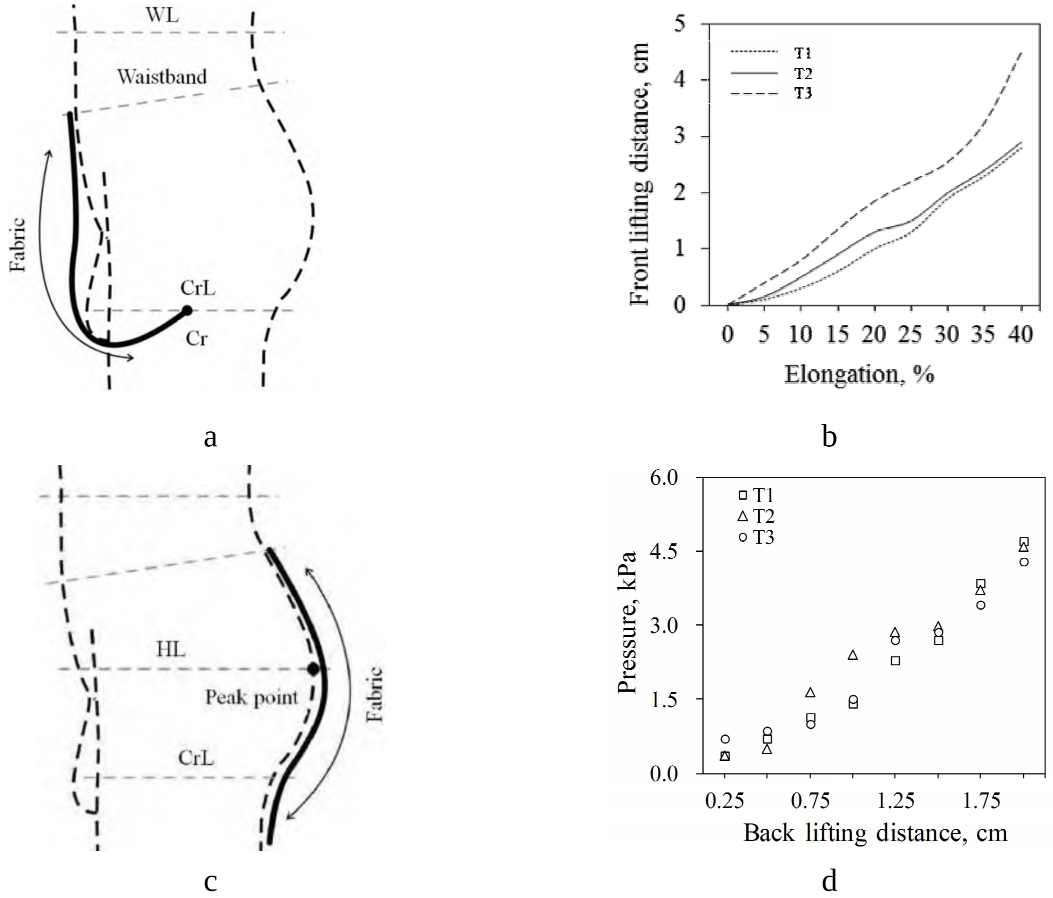


Figure 4.8 – Vertical test: a– lifting on front; b – relation between material strain and lifting on the front; c – lifting on hips; d – relation between material strain and push-up effect on the hip

4.3. Pressure test on the male body

In this stage of the experiment, the following human body parts are measured: biceps, forearms, natural waist, waistband (4cm below navel), thighs and calf. At the same time, we measure the measured data directly to *Excel* format with four sensors. Each circumference has six measurement points, limbs have four measurement points

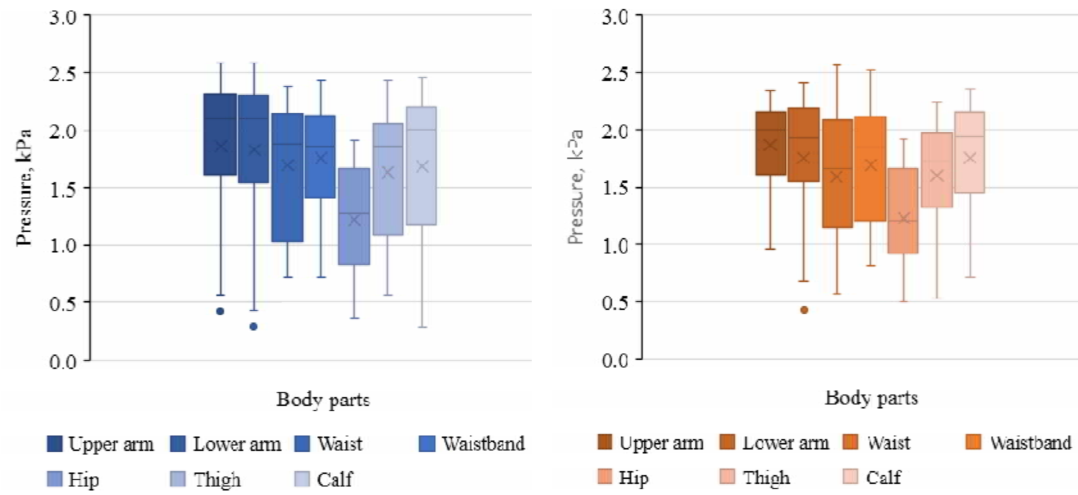
a b c

Figure 4.9 – Pressure test on the body: a – “shell” with scale; b – measure on waist; c – measure on the upper arm

The measured data and estimated values briefs are shown in Table 4.2. We have recorded the pressure and soft tissues thickness of each tested position and calculated the error value of each measurement [282-285]. Table 4.2 shows the measurements of compression pressure in different positions.

Table 4.2 – Values of measurable indexes for male body

Measurements, unit		Interval	Error
Average maximum pressure on body P_{body}, kPa		0…2.48	± 0.33
Thickness of soft tissues, cm	Upper arm	0.8…1.2	± 0.20
	Lower arm	0.7…0.9	± 0.10
	Natural waist	1.5…2.5	± 0.51
	Waistband	0.9…1.4	± 0.26
	Thigh	1.0…2.2	± 0.61
	Calf	0.8…1.5	± 0.36



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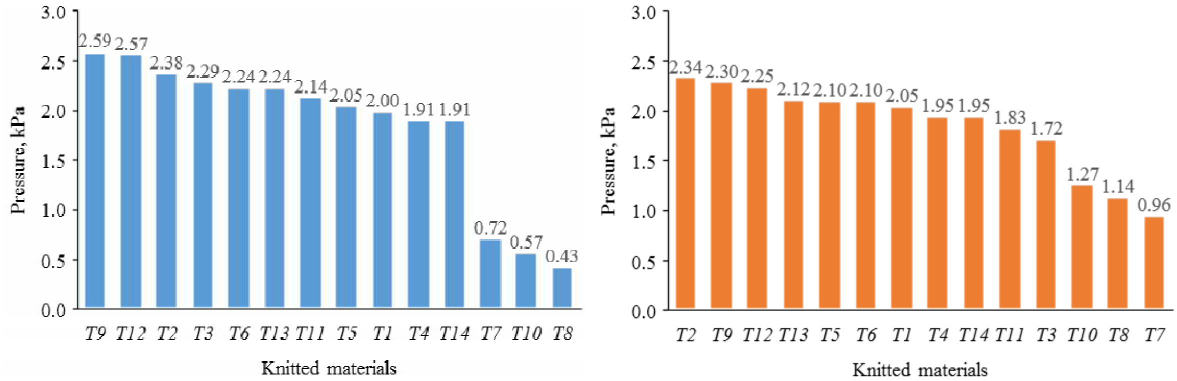
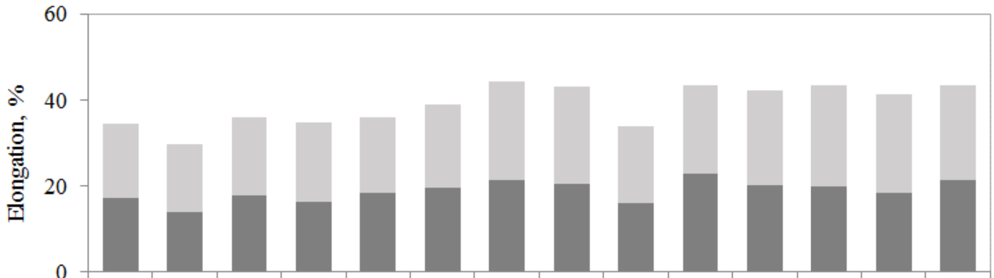


b

Figure 4.10 – Maximum pressure (left is pressure in the material's warp, right is in the weft):
a – P_{body} on 7 body parts; b – P_{max} by different materials



	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14
Weft	17.22	15.56	18.06	18.33	17.78	19.44	22.86	22.62	17.86	20.71	22.14	23.57	22.86	22.14
Warp	17.14	14.05	17.86	16.42	18.33	19.53	21.43	20.48	15.95	22.86	20.24	20.00	18.57	21.43

Knitting materials

Figure 4.11 – Knitted materials elongation at the maximum pressure on body

As shown in Figure 4.10 a, P_{body} is the average maximum accepted pressure value on soft tissues of 7 body parts in two directions warp and weft of knitted materials, kPa. As shown in Figure 4.10 b, P_{max} is the average maximum pressure of materials in different elongation states, and 14 kinds of materials concentrate on the pressure and elongation of materials in 7 different parts of human body. The pressure values of 14 materials are arranged in order of magnitude. Figure 4.11 shows the elongation at the average maximum tensile strength (E_{max}) on body parts in the warp/weft, and the maximum pressure P_{max} at the same time.

4.4. Analysis of knitted material properties

Men and women have different underwear. As same as the bra, it has a strong practical function. There is a particular spatial relationship between the bra’s “cup” and front insert area, which offer some supporting function. Therefore, this part of the design is the key point, reasonable structural design meets the static and dynamic requirements with a comfortable feeling. In recent years, because of the application of unique materials and nanotechnology, underwear can bring many therapeutic and health effects, and is also very popular in recent years. For example, the “HAOGANG” brand, a popular brand of Chinese healthcare underwear in Russia, has the functions of shaping, improving blood circulation, eliminating inflammation, restoring reproduction, urinary system and so on.

The design and development of modern men’s underwear can be divided into simple transition periods: visual impact; material performance improvement; changes in style function.

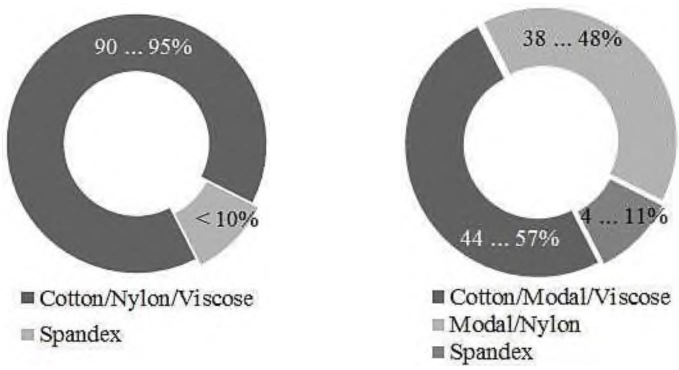
(1) Decoration. From the aesthetic point of view of underwear, designers already in the 70 years began to focus consumers’ attention on the design of the logo of the belt.

(2) Style. Different underwear materials influence underwear’s appearance, styles. Elastic underwear surpasses regular loose-fitting cotton underwear with lower elasticity. The reason is that the unique features of the line structure bring excellent visual effect, and good personal fitness effect makes the underwear and body as a whole and makes consumers more satisfied. The fascination with fitness, and the cult of a healthy body also influenced the change in the structure of underwear, first, from the position of the fit with the plastic and the shaping of the overall male image, the dynamic contour and line division (Figure 4.12 b).

a b

Figure 4.12 – Different style of men’s underwear: a – daily life; b – sports

According to the network resources, we investigated the domestic and foreign male underwear sales outlets and official website product information. By retrieving the top 2 or 3 items of underwear from 2013 to 2014, we found the main ingredients. As shown in Figure 4.13.



a b

Figure 4.13 – Modern underwear compositions: a – first group of composition; b – second group

Through the components calculate of the sales of men’s underwear in the Chinese and international brand. Underwear is made of pure cotton (or 90…100%) material. Model and other elastic materials followed. The 5…10% spandex is basically maintained in the auxiliary composition to maintain the elasticity and firmness. Through the statistics of Chinese and international brands of men’s underwear ingredients. Underwear is mostly made of pure cotton (or 90…100%) materials, followed by Modal and other elastic materials. The 5…10% spandex is basically kept in the auxiliary composition to maintain elasticity and firmness. Cotton underwear is highly hygroscopic but not moisture permeable and has poor elasticity, if the skin contact with wet clothes for a long time, can easily develop scrotum redness, itching, hot rash or eczema, and dermatitis. Therefore, if want to wear cotton underwear, should ensure that the dryness of underwear, men who sweat easily and drive more often is not fit to wear cotton underpants. The elasticity of cotton is weak, the fit of cotton underwear will be greatly affected (improper wearing easily affects the normal development of adolescent reproductive organs). So combed cotton underwear is the best choice and the addition of 5% to 10% spandex (DuPont’s Lycra) as an adjuvant to increase the elasticity of underwear and enhance fit.

So far, in the underwear market, cotton, and regenerated cellulose fiber materials are the main promotion and production of raw materials, but some new underwear materials are also not to be underestimated. The functional, decorative or comfortable underwear have their own characteristics and good performance, which has an inseparable relation with their superior performance parameters.

4.4.1. Methods and devices for testing materials

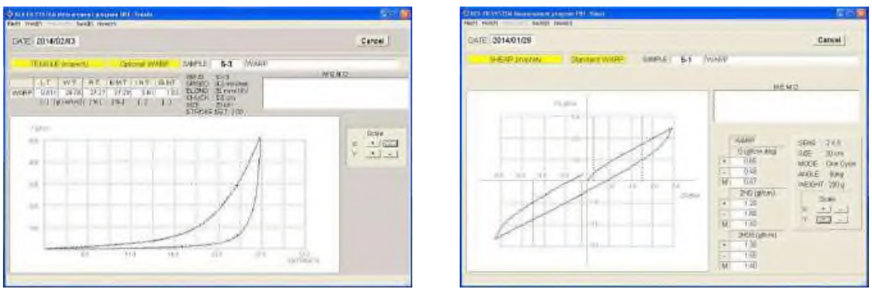
In our study, the KES (Kawabata System, KATO TECH Japan) test system is designed by the Kyoto University Professor *Kawabata Tetsuya*. In our tests, we took automatic instruments of KES-FB1 (tensile shear), KES-FB3 (compression) and KES-FB4 (surface), and use the curve characterization to adequately reflect the properties of knitted material in the low stress and strain of the tensile, shear, and compression processes.

The material samples have been cut to 20*20cm in order at the edge 5cm of the material. Its main composition as shown in Appendix III, Table III.2. Each material is tested ten times, including five horizontal tests and five longitudinal tests. Mark each experiment number, such as 5-1 to 5-5 for the horizontal test; 5-6 to 5-10 for the longitudinal test. The wrong side of the material will be in direct contact with human skin, so the test uses the material wrong side which contact the human surface for testing.

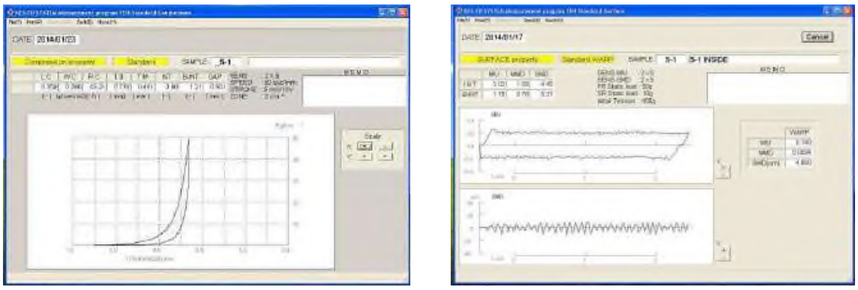
(1) KES-FB1 tester is used for tensile and shear test, sample size 20*20 cm. The maximum tensile load was 500 gf/cm (cN/cm). ***LT*** – tensile rigidity, values closer to 1 mean firmer tensility; ***RT*** – recoverability, %, values closer to 100 mean better recoverability; ***WT*** – tension energy, cN.cm / cm^2, higher values mean greater stretchability; ***EMT*** – elongation at 500 cN / cm load, %, the larger the value, the better the extensibility. Generally, the higher the index value, has the better properties of extensibility and elastic resilience of the knitted material.

The sample sizes for shear were same and the maximum shear angle was ± 8° with the tension of 10 gf/cm. For example, at 5%: tensile *F* is 25 gf/cm, shear *F* is less than 3.6 gf/cm in both directions. The shear rigidity (*G*) is the slope of the shear stress-strain curve: $G = F / \tan \theta$. ***G*** – shear rigidity (between shear angles ± 0.5 to ± 2.5°), cN / [cm·(°)], the larger the value, the material harder; ***2HG*** – hysteresis of shear force at 0.5°; ***2HG5*** – hysteresis of shear force at 5° cN/cm, the smaller these two values, the material has better the deformation recovery ability, the material more flexible and soft. The lower the index value, the better the properties (material handle value) of flexibility and softness [6].

Figure 4.14 – KES-FB1..4 equipment



a b



c d

Figure 4.15 – KES-FB1 diagram: a –Tensile Tester KES-FB1; b – Shear KES-FB1; c – Compression Tester KES-FB3; d – Surface Tester KES-FB4

(2) KES-FB3 is used to measure the compressibility and thickness. The instrument is moved to change the measurement position and detected in three different positions automatically. The platen area is 2 cm^2 (circle). According to the test standard, the highest detection sensitivity is 1μ, compression minimum load detection is 10 gf/cm^2, the maximum is 50 gf/cm^2, and the rate is 0.02 mm/sec. ***RC*** – recoverability of compression, %, values closer to 100 mean better recoverability, the better the thickness durability and the fullness of the hand feeling; ***WC*** – compression energy, the larger the value, material is more fluffy and thick; ***LC*** – linearity of compression and material thickness, values closer to 1 mean firmer compression (the thickness of the material decreases linearly with increasing pressure, the *LC* = 1) [62], $cN \cdot cm/cm^2$, the more easily the material is compressed and deformed, the thicker the handle; $\boldsymbol{T_0}$ – material thickness under the pressure 0.5 cN/cm^2, mm; $\boldsymbol{T_m}$ – material thickness under the pressure 50 cN/cm^2, mm. Generally, the higher the index value, t the better the feeling of bulkiness and spongy property (material handle value), the compressibility has some correlation with the thickness (***T***) of the material; more thickness, the higher the compressibility [135].

(3) Surface properties were tested by KES-FB4. The instrument moved to measure 3 positions automatically with a plate area of 0.25 cm^2, the test area is 20*5 mm, the moving speed is 1 mm/sec., and the friction measurement with vertical load 50 gf, roughness measuring force is under pressure 10 gf. ***MIU*** – frictional coefficient; ***MMD*** – deviation of average friction coefficient); ***SMD*** –

surface roughness, µm. Generally, the lower the index value, the more smooth the surface, and the flatter the weave of the material structure.

4.4.2. Parameterization of indicators of properties of knitted materials

Through the KES test and contrast, the physical quantity reflecting the style features can be obtained to evaluate the quality of materials [286]. Such as the friction and extensibility between underwear material and human body skin, it affects the comfort of underwear wear. When the extensibility of the material is weak, and the friction is large, it will produce a great feeling of squeezing on the human body; on the contrary, it will be better. However, material resilience and soft thickness will also have a more significant impact on the comfort of underwear.

T_7, T_8, T_{10}, T_{12}, T_{13}, T_{14} samples have well tensile properties, and the tensile properties are apparently higher than those of other knitting materials. It is soft because of its high content of micro Modal or polyethene fiber; it has high elasticity and drapability, smooth appearance and handle, excellent extensibility, and high resistance, easy cleaning and high durability. T_7, T_8, T_{12}, T_{14} samples have well shear properties, but T_{12} is the best. They are more flexible and softer with higher recoverability, stability. T_1, T_5 are combed entirely with Modal, cotton, the structure is Pique knitting materials, so the flexibility and surface smoothness are poor. However, t the chemical composition of cotton and viscose fiber is similar, their moisture content is most in line with the physiological requirements of human skin, and they have good air permeability, dyeing performance, color fastness and humidity adjustment function, so they are not easy to produce static electricity. So the designer preferred material in the visual design of the product. However, it is better to select the combed cotton and add more elastic fibers such as Modal or spandex to improve the elasticity and fit.

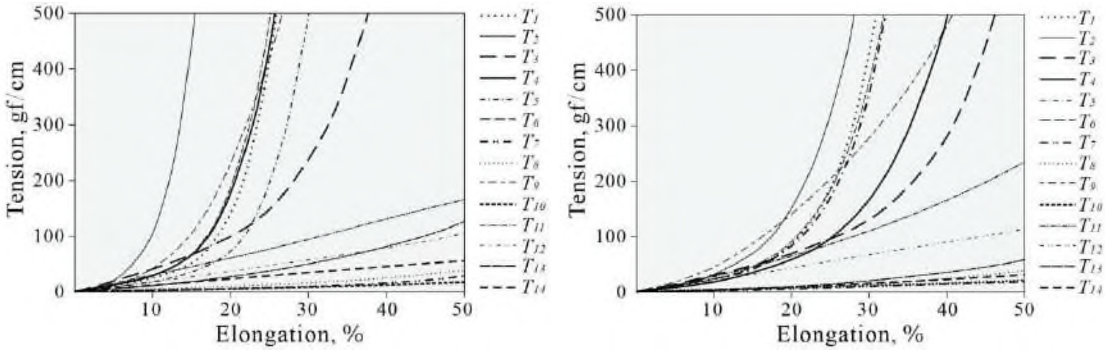
4.5. New indexes reflect the real situation system "body-underwear"

4.5.1. Analysis of tensile property

Due to people's breathing and various dynamic behaviours, tight elastic clothing material will produce specific changes to the human body. The material follows the human skin stretching shrinkage and produces a certain degree of short or long time stretch deformation process, the process of material deformation continues to accumulate, eventually resulting in elastic material ease, not enough to provide the human body comfortable pressure. The tensile test of KES is the material under low stress, which mainly evaluates the elongation, deformation and tensile recovery of the material. There are various movements of limbs in daily life, and different degrees of deformation occur at various parts of the body. If the material can adapt to these deformations and can recover, it will make the person feel comfortable; otherwise, the material will impede human activity, bring some feeling of oppression, and make people feel uncomfortable. It can be seen that the tensile properties of knitted underwear material play an important role in the functionality and comfort of underwear.

(1) As shown in Figure 4.16, we only showed the elongations of the knitting materials are less than 50% under tensile force at standard load 500 cN/cm, which can be compared with the tensile-strain properties: in the warp direction, materials have a bigger difference with the others. T_2 is mostly close to the vertical line when elongation is more than 10% with the poorest elasticity. T_7, T_8 and T_{10} are closely and have good elasticity with the lowest tensile force.

In total, all knitting materials of the underwear can be elongated 20% below 200 gf/cm tensile force. All materials were departed into two groups, seven kinds of materials' curves are relatively rose sharply between 10 to 40%, and others 7 rose steadily approach to 100% in averagely. In the weft direction, it is evident that all materials have good tensile properties and can be more than 30% on the whole.

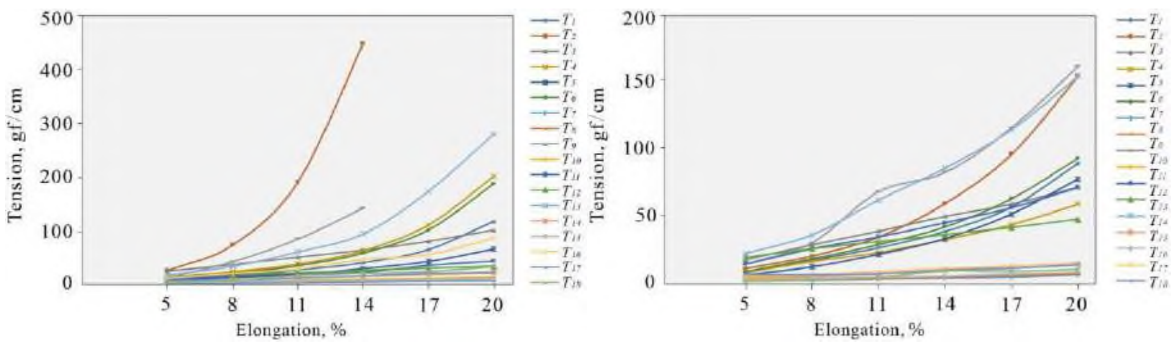


a b

Figure 4.16 – “Tension-strain” tests: a – in warp; b – weft

(2) The tensile force under low elongation (Appendix IV, Figure IV.1 to IV.18). The samples curves were redrawn (Figure 4.17). According to the tests on the human body, E_{max} are between 14.05...22.86% (mean is 18.88%) in warp direction; and 15.56...23.57% (mean is 20.08%) in the weft direction. In total, the average value of two directions is between 14.80…22.15% (mean is 19.48%).

Therefore, the elongation of the experimental samples should refer to the interval 5...20%, the material pressure values are difficult to be measured during 0…5%, the maximum elongation on the human body is over 20%, based on the different elastic properties of materials we can take 14.8...22.2% for design to meet the human skin deformation (between 0…40.28%) for comfortable.



a b

Figure 4.17 – Diagrams of “load-strain”: a – in the warp; b – in the weft

As shown in Figure 4.17, we analyzed the relationships between tensile force value and the particular elongation. Our values for *F* were taken from elongation *E* 5% to the maximum, a study with an interval of 3%, are *f* {5, 8, 11, 14, 17, 20%}. $F(E_{max})$ is the maximum tension force of the material tested on the human body under the maximum elongation (Appendix IV, Table IV.3).

As showed in Figure 4.17 that the T_2 has significant differences with others, and T_9 cannot be over 14% in the warp, increase quickly during *F(17)* to *F(20)*.

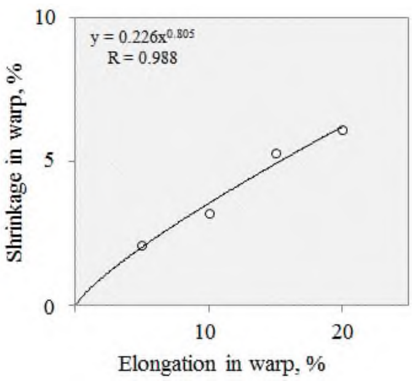
When the elastic knitted material is stretched in one direction (warp), the other vertical direction (weft) will shrink to a certain extent. We cut samples of our 18 knitted material to 14*10 cm and used a material stretch tester with clamping both sides 2+2 cm, so the test size of the material sample is 10*10 cm, as shown in Figure 4.18.

a

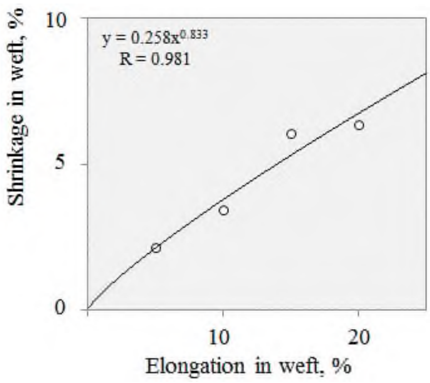
b

Figure 4.18 – Shrinkage test: a – original; b – after a stretch

After the test, we calculate all data (Appendix IV, Table IV.4), the average materials shrinkage are 5.42% in the warp, and 6.12% in the weft (Figure 4.19). The materials T_7, T_8, T_{12} have large shrinkage during 20...36% elongation in the warp, 15...25 % in weft; T_3, T_6, T_{11}, T_{13}, T_{14} have smaller shrinkage during 0...2% in warp and weft; T_5, T_{16} have smaller shrinkage during 0...2% in the weft.



a



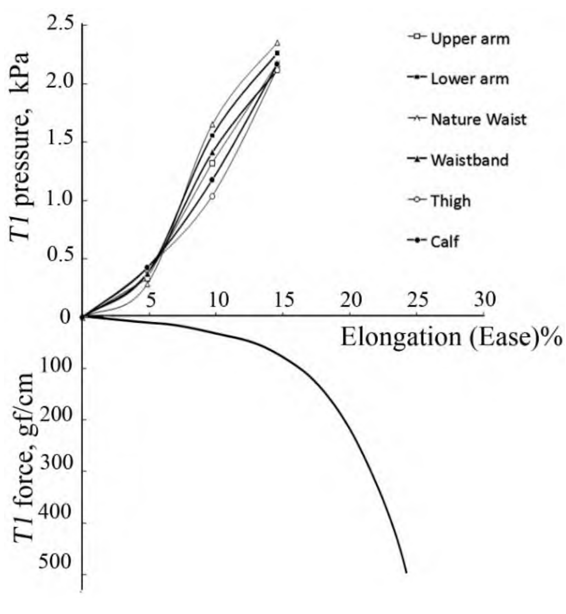
b

Figure 4.19 – Relationships between elongation and shrinkage: a – warp; b – weft

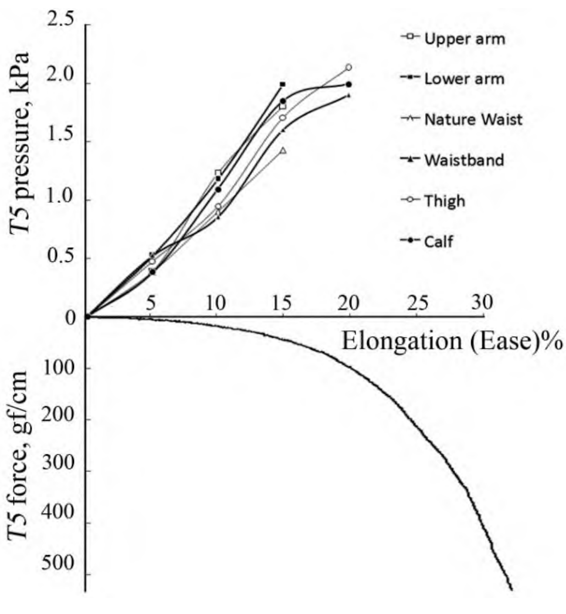
4.5.2. Elongation and compression of the material

Figure 4.20 shows the diagram of test data pressure and tension of knitted materials T_1 and T_2. The horizontal X-axis of the diagram is tensile-strain test data of knitted materials. The lower part of the Y-axis is the experimental data of tensile stress (force) of knitted materials, and the upper part of the Y-axis is the upper part of the pressure test data of knitted materials. The tensile in the diagram is proportional to the trend of compression pressure. In the study of tensile mechanical properties of knitted materials, we only need to consider the tensile degree of knitted materials under low load.

As shown in Figure 4.20, the following important conclusions are obvious. Skin tissues are differently susceptible to compression pressure: under the material T_1. It is possible to reach the highest pressure of 2.1...2.5 kPa under the material of T_5 1.7...2.2 kPa. To compress the soft tissues of the figure, the materials should be stretched to different values: for the material T_1, the limiting value is 15% elongation value, and for the T_5 material, the value is between 15 and 20%.



a



b

Figure 4.20 – Relation between strain, pressure value and tensile force: a – T_1 comparison diagram; b – T_5 pressure and tensile force

The "force-stretching" curves obtained from the KES-FB-1 device allow obtaining additional information on internal stresses. With the same elongation 15% of the samples, different stresses will act inside them: in the material T_1 – 65.0 cN/cm, and in the material T_5 – 31.3 cN/cm.

4.5.3. Development of an indicator for assessing the compressive performance of knitted materials

To realize the “human body - knitting material” system with comfortable pressure, the ease allowance should not only be designed according to the knitting material’s pressure ability but also depends on the knitting material structure, which will have different effects on human skin. Therefore, a new reference index is proposed from the “human body - knitting material” system. Expressed as: knitted material compression performance index – *CP* compressive performance

$$CP = (P_{\text{max.warp}} + P_{\text{max.weft}}) / (E_{\text{warp}} + E_{\text{weft}}), \quad (4.1)$$

where E is ease allowance, the contrary value (negative value) for tight-fitting underwear design, %, $E = 100 \cdot [(CS - BS) / BS]$, BS is body size, the human body circumference size, CS is clothing size); P_{max} is the maximum allowable pressure under a stressed knitted shell, kPa; CP is a reflection of the knitting material’s pressure ability for underwear, $0 < CP \leq 1$, kPa/%; the higher the value, the knitting material’s pressure ability is stronger, no need to design more ease allowance (negative value) to make tighter (obtain greater pressure), so that, the lower the value, the knitting material’s pressure ability is pressure ability is weaker.

However, the new index *CP* – relations between the maximum elongation of knitted materials (%) and reasonable compressive pressure (kPa) – the feeling on the lower part of the body, kPa/%, and this index is important for applications on the different parts of underwear patterns. Though our tests of the knitted materials, we have known the acceptable maximum ease range during the reasonable compression pressure is less than 3.192 kPa in short-time. So, we can use it in the pattern at the different girth, E.g. if one sample of material *CP* = 0.130 kPa/%, which means it can provide 0.130 kPa to the soft tissue of body when we the ease decrease in 1 %, if the original W_G = 80 cm, we decrease it by 10 %, then it is 72 cm and will be provided with 1.302 kPa at waist part. This can help people to select the acceptable extensibility of knitted materials, with clear pressure.

As Figure 4.21 shown, left y-axis is *CP*, the right upper y-axis is pressure, and lower is elongation. We can see the good elongation performance of materials have a relatively low average pressure value, such as T_7, T_8, T_{10} *etc*., so that their *CP* are also lower as blue and orange lines shown

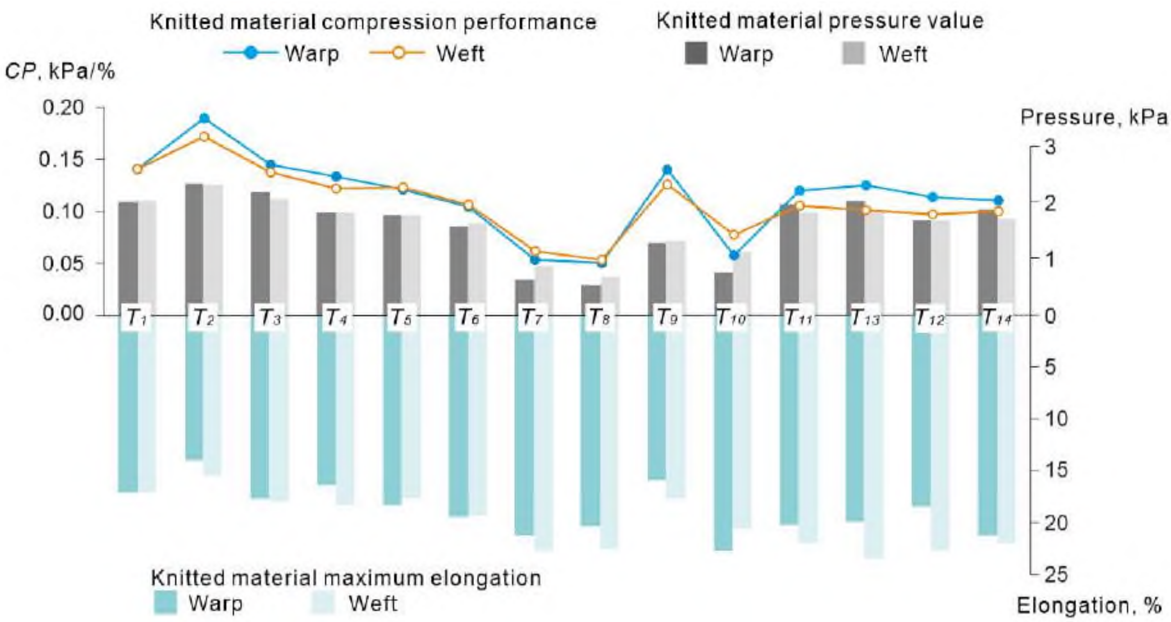


Figure 4.21 – Relations between compressive performance and pressure, ease

4.5.4. Dividing knitted materials into four levels

As shown in the Table 4.3 and Figure 4.21, some of the knitted materials belong to different levels in warp and weft directions.

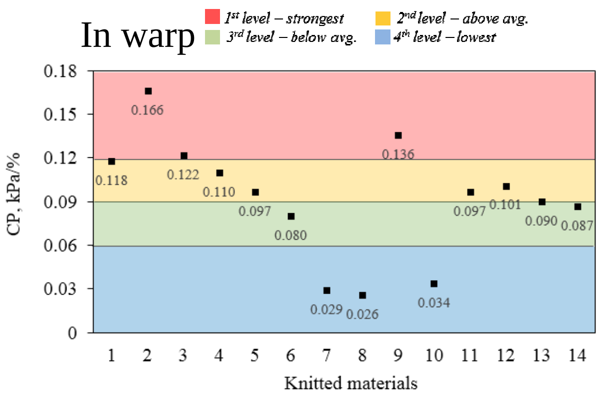
We divided knitted materials between four levels from high to low in according with its *CP* indexes:

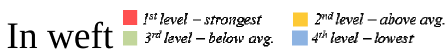
- 1st level includes the materials with the strongest compression when *CP* equal and more than 0.12;
- 2nd level includes the materials with above average compression when $0.09 \leq CP < 0.12$;
- 3rd level includes the materials with below average compression when $0.06 \leq CP < 0.09$;
- 4th level includes the materials with the lowest compression performance when *CP* equal and less than 0.06.

Only a few knitted materials' have very high or low *CP*, so we narrowed the middle level area. Table 4.3 shows the materials distribution marked red-orange-green-blue colors

Table 4.3 – Four levels of *CP* values

Material	*Warp*	*Weft*
T1	0.118	0.118
T2	0.166	0.149
T3	0.122	0.114
T4	0.110	0.099
T5	0.097	0.100
T6	0.080	0.083
T7	0.029	0.038
T8	0.026	0.030
T9	0.136	0.114
T10	0.034	0.054
T11	0.097	0.082





T12	0.101	0.078
T13	0.090	0.074
T14	0.087	0.077

1st level – strongest *2nd level – above avg.*
3rd level – below avg. *4th level – lowest*

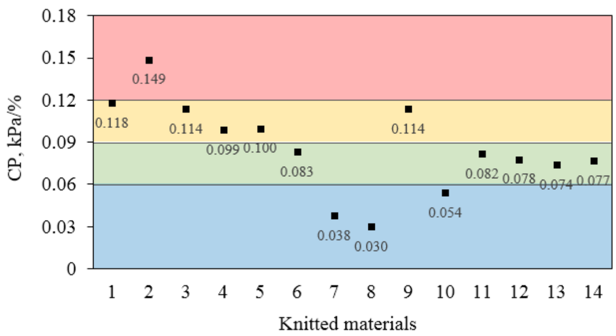


Figure 4.22 – Kinds of knitted materials

4.5.5. Comparison of indexes of compression performance

We compared the *CP* indexes with the $К_{компр}$ proposed by I.Tislenko (Ilya Tislenko, 2017 [272]) of twelve knitted materials and marked them in order from T_1 to T_{12}.

To analyze the differences between the both, we have considered next factors: (1) average values of calculated indexes; (2) accuracy of pressure predicting; (3) conditions of measurements.

(1) Table 4.4 shows the average indexes calculated by 12 kinds of knitted materials in different approaches.

Table 4.4 – Average values of 12 knitted materials compression ability, kPa/%

	$CP = P_{max} / E_{max}$, kPa/%			$К_{компр} = d(P_1+P_2) / 2d\sigma^*(\Delta\sigma/\Delta\varepsilon)$ kPa/%		
	CP, warp	*CP*, weft	Avg. *CP*	$К_{компр}$, warp	$К_{компр}$, weft	Avg. $К_{компр}$
Mean	0.093	0.088	0.091	0.238	0.109	0.173

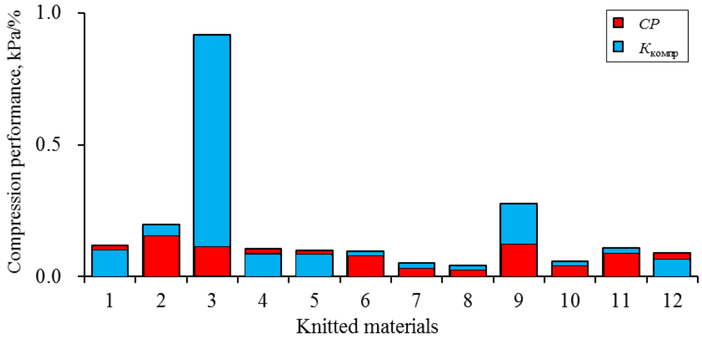
*wherein E_{max} and $\Delta\varepsilon$ – the knitted material elongation (strain in KES); P_{max}, P_1 and P_2 – pressure value; $\Delta\sigma$ – the stress force in KES

The average *CP* is 0.091 kPa/%, nearly half the value of $К_{компр}$ (0.173 kPa/%). We can see that average values of *CP* in warp and weft are more balanced. Because the units of both indexes are the same kPa/%, it is reasonable to produce a pressure of 0.091 kPa for knitted material per 1% elongation.

Figure 4.23 shows the comparison of both indexes data for 12 sets of materials, and correlation analysis.

As can be seen from Figure 4.23 a, there are significant differences at No.3 and 9. And eight indexes $К_{компр}$ are higher than *CP* value. Moreover, the correlation analysis between *CP* and $К_{компр}$ was also used to prove the irrelevance of the two sets of data (12 indexes per set) by a bivariate analysis

(Figure 4.23 b).



a

Correlations

		CP	Ккомпр
CP	Pearson Correlation	1	.408
	Sig. (2-tailed)		.188
	N	12	12
Ккомпр	Pearson Correlation	.408	1
	Sig. (2-tailed)	.188	
	N	12	12

b

Figure 4.23 – Comparison of indexes of compressive ability (*a*); Bivariate analysis of both indexes by SPSS (*b*)

The crucial correlation coefficient is r = 0.780 for n = 12 and the level of probability is 99.9% (0.001) in according with Bolshev-Smirnov statistical handbook. The result shows as a common fraction, where the Pearson correlation coefficient is r, *sig*. is p-value, the significance of the test. If the p-value is less than the chosen significance level ($\alpha < 0.01$, two-tailed), it suggests the observed data is sufficiently significant for their correlation. However, we can see from the calculation results, the both of indexes are uncorrelated and not significant. Therefore, the results between the two sets of data are irrelevant, detailed analysis of the next step can be performed.

(2) Table 4.5 shows the comparison of pressure prediction and the relative error calculated by both average indexes, the values of elongation E_{max} and pressure P measured. The measured results based on human test results on same measuring positions – waist, high hips (wasitband), hips and thigh.

We can see from Table 4.5, according to experimental results, the average relative error is only 31.51% between $\widehat{P}_1$ and P, and the maximum relative error is 220.32%. But the average relative error calculated by $K_{компр}$ is 150.01%, and the maximum relative error is 508.97%. Moreover, the results of $\widehat{P}$ are 1.746 and 3.319 kPa respectively. Obviously, the results of $\widehat{P}_1$ is closer to the actual measured value P. Because in the tests, P is almost the maximum acceptable pressure for the human body under the stretch of the knitted material.

Likewise, Table 4.6 shows the comparison of pressure prediction and the errors calculated by both average indexes (based on respective test results), the values of E_{max} (and pressure) measured from body parts. As for the experiment data, only select the same body parts of the test data for comparison. $E_{max.1}$ measured on four parts of the male body and $E_{max.2}$ measured on four parts of female body.

Table 4.5 – Comparison of two methods of pressure prediction

Mate-rials	*Avg.* Max.elo-ngation, %	Real pressure, measured on human soft tissues, *P*, kPa	Theoretical pressure $\hat{P}$ calculated by equations, kPa		Difference between real and predictable pressure, the relative error δ, %	
			$\hat{P}_1 = CP \cdot E_{max}$	$\hat{P}_2 = K_{компр} \cdot \Delta\varepsilon$	$\delta_1 = \lvert\hat{P}_1 - P\rvert / P \cdot 100\%$	$\delta_2 = \lvert\hat{P}_2 - P\rvert / P \cdot 100\%$
T_1	17.18	2.021	1.564	2.972	22.65	47.06
T_2	14.80	2.328	1.347	2.561	42.12	10.03
T_3	17.96	2.116	1.634	3.106	22.79	46.78
T4	17.38	1.814	1.581	3.006	12.82	65.73
T5	18.06	1.778	1.643	3.124	7.60	75.67
T6	19.49	1.596	1.773	3.371	11.12	111.26
T7	22.15	0.753	2.015	3.831	167.65	408.82
T8	21.55	0.612	1.961	3.728	220.32	508.97
T9	16.91	2.098	1.538	2.925	26.68	39.39
T10	21.79	0.948	1.983	3.769	109.09	297.51
T11	21.19	1.890	1.928	3.666	2.03	93.98
T12	21.79	1.934	1.983	3.769	2.53	94.92
Mean	*19.19*	*1.657*	*1.746 ± 0.224*	*3.319 ± 0.425*	*31.51 ± 85.55*	*150.01 ± 162.64*

Table 4.6 – Comparison of two methods of pressure prediction

Body parts	*Avg.* $E_{max.1}$, %	Difference between real and predictable pressure,		*Avg.* $E_{max.2}$, %	Difference between real and predictable pressure,	
		Absolute error Δ, kPa	Relative error δ_3, %		Absolute error Δ, kPa	Relative error δ_4, %
Waist	19.1	0.054	3.23	14.1	0.839	52.17
Waistband	20.4	0.126	7.30	23.9	0.770	22.94
Hip	23.1	0.864	69.84	22.7	0.984	33.40
Thigh	17.9	-0.003	0.17	8.7	0.068	4.69
Mean	*20.1*	*0.260*	*20.14*	*17.4*	*0.665*	*28.30*

Then, we can see from Table 4.6, we tested different body parts, the maximum measured elongations were different. According to $E_{max.1}$ experimental result, the average relative error is 20.14%. But the average relative error of $K_{компр}$ is 28.30%. Moreover, the absolute errors are 0.260 and 0.665 kPa respectively. So, the results calculated by *CP* is closer to the actual measured pressure value, there is only a large error in the soft tissue part of the buttocks.

(3) Besides, the differences between both indexes are depending on the differences of experiment subjects, methods, purposes and the accuracy of pressure prediction. Table 4.7 explains the aspects of different approaches.

By comparison, index *CP* was completely based on human body sensitivity/comfort and represents the maximum compression performance. $K_{компр}$ is an idealized prediction that sets the compression possibilities within a small interval. And all the measured values used to calculate are not from the real human bodies, index $K_{компр}$ is obtained only based on simulating the soft parts of the human body on a silicone cylinder, and then verified the pressure results on female bodies and found the difference between the predicted pressure value and the actual measured value is ± 0.53.

Table 4.7 – Comparison of the indexes for material compression ability presenting

No.	Aspects	Methods of conditions getting		Comparison
		Existing $K_{компр}$	Proposed *CP*	
1	Object measured	Silicone cylinder	Real human body	*CP* can be applicated to each cylindrical parts of male body. $K_{компр}$ just simulates soft tissue of the human body.
2	Criteria of human body sensitivity getting	Until to the corrective effect close to the maximum value of 6 body parts.	Until to the tester feels uncomfortable (very tight) at 7 part of the body.	*CP* based on body sensitivity, the E_{max} value that can be calculated by pressure sensitivity. $K_{компр}$ based on $P(\sigma(\varepsilon))$, pressure influenced by dependency $\sigma(\varepsilon)$.
3	Subject measured	Recording stress force and pressure, and recording stress force and strain on KES.	Recording two max. values – max. elongation and max. pressure (generated under max. elongation) simultaneously.	*CP* is convenient to measure and calculated, based on the feeling of the testee. $K_{компр}$ based on ε (elongation) approximately 20.0%, it needs two ways of calculation and measurement.
4	Applicable situation	Express the linear approximation of $P(\varepsilon)$ in the proximity of ε = 20%.	Express the max. compressibility performance of the knitted material.	*CP* used to estimate the max. pressure of a knitted material which can apply to the human body under different design ease. It can be used for classification and selection of knitted materials.
5	The accuracy of prediction compression pressure on the human body, kPa	The error ± 0.53, the range is 0.01…0.98. Measured on female bodies.	The error is ± 0.10, the range is -0.17…0.86. Measured male bodies.	We conducted pressure prediction calculations based on our respective data, the difference between our predicted value and the actual pressure is ± 0.44.

The study of material compression performance and tight-fitting clothing cannot be confined to the mannequin experiment but must be combined with the actual human body. Therefore, it is necessary to conduct the test method with the actual body’s pressure sensitivity and obtain reliable results. Moreover, the calculation method of *CP* is simple, it can be obtained by measurement on the human body (it mainly focused on the soft tissue of the male lower torso). And *CP* is more accurate in predicting pressure and can classify knitted materials in terms of compression performance. As for the characteristics of the knitted materials and the pressure tolerance of real human soft tissues, the maximum pressure value predicted by $K_{компр}$ is too large, and there is a big gap between the predicted value and the actual measured value. According to our test experience, these such large pressure values will appear in some hard or bone parts of the human body.

4.6. Mathematical models for predicting pressure

The pressure performance of knitting material samples is predicted [287-295]. The experimental data obtained from the mechanical properties of knitted material samples and the pressure data test on male body are divided into "original data" and "selected data". The mechanical data of material measured by KES have a significant correlation with P_{max} and *CP*. "Original data" is directly measured from knitting material mechanical data, and "selected data" is selected from the knitted material stretch performance test (stress-strain). We made bivariate analysis by *SPSS*, and analyzed the correlation of the knitted material maximum pressure value, *CP* and test data, the results are shown in Table 4.8…4.10 (Appendix IV, Table IV.5).

As shown in Table 4.8, we chose the probability level at 0.05 (95%), for samples of material n = 18, the crucial correlation coefficient is $r = 0.444$, $sig. < 0.05$. The data underlined represent warp; bold represent strong correlation and highly significant. All data have good correlations, but some of them have low significant. *F(5)*, *F(8)* have the strong correlations with maximum pressure and *CP*. Moreover, in weft direction the *F(5)*…*F(11)* have strong correlations with the pressure and *CP*, in warp the *F(5)…F(11)* have strong correlations with the pressure, because the knitting material samples are less stretchable in the warp direction.

As shown in Table 4.8, we chose the probability level at 0.05 (95%), the crucial correlation coefficient is r = 0.497, *sig*. < 0.05. $P_{\max}$ and *CP* have very strong correlations and highly significant with *EMT*, T_0 and T_M and friction property SMD.

Table 4.8 – Correlation coefficients between the KES properties and $P_{\max}$, *CP* (wrap/weft)

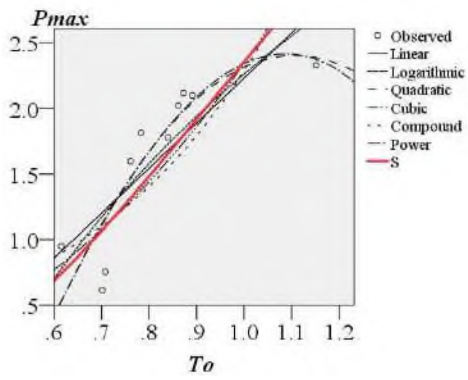
Index	$P_{\max}$	*Sig.*	*CP*	*Sig.*
EMT	-0.604	*0.022*	-0.740	*0.002*
	-0.696	*0.006*	-0.774	*0.001*
F(5)	**0.708**	*0.002*	0.759	*0.002*
	0.621	*0.018*	0.495	*0.072*
F(8)	0.685	*0.007*	**0.813**	*0.000*
	0.701	*0.005*	0.610	*0.021*
G			0.595	*0.025*
			0.537	*0.048*
T_0	**0.816**	*0.004*	**0.876**	*0.001*
T_M	0.768	*0.009*	0.844	*0.002*
SMD	0.542	*0.106*	0.507	*0.135*

On one hand, because the *P* pressure value provided by elastic knitted materials is in a certain range (have the limit maximum range), thus we use S-curve (sigmoid function), power or liner models to approach for modeling the relationship between pressure and knitting material properties separately, the following (x_i, y_i), the independent variable x_i is knitting material properties, the dependent variable y_i is maximum accepted pressure; on the other hand, the multivariable linear regression model was established for another modeling,

$$y_i = e^x = exp\{f(x)\}, \quad (4.2)$$

$$y_i = \beta_0 1 + \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_n x_{i1n} + \varepsilon_i, \quad (4.3)$$

where y_i is the dependent variable of pressure, e is the natural base; x_{i1}, x_{i2}, …, x_{in} is independent variables of knitting material properties, $i = 1, 2, ..., 18$, $x \neq 0$, $y > 0$, β_0 is the constant term, ε_i is the random error (random variable) term.



a

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.800	.640	.595	.305

The independent variable is T0.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	1.323	1	1.323	14.228	.005
Residual	.744	8	.093		
Total	2.067	9			

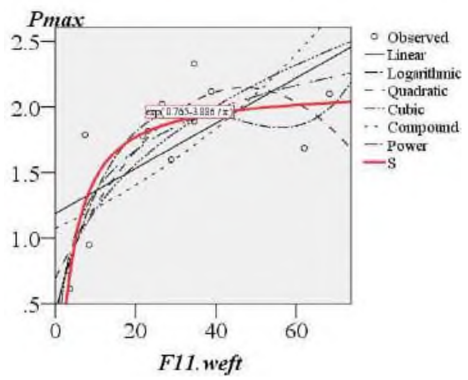
The independent variable is T0.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 / T0	-1.853	.491	-.800	-3.772	.005
(Constant)	2.709	.624		4.344	.002

The dependent variable is ln(Pmax).

b



c

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.905	.819	.804	.182

The independent variable is F11.weft.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	1.811	1	1.811	54.482	.000
Residual	.399	12	.033		
Total	2.210	13			

The independent variable is F11.weft.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 / F11.weft	-3.886	.526	-.905	-7.381	.000
(Constant)	.765	.065		11.750	.000

The dependent variable is ln(Pmax).

d

Figure 4.24 – Sigmoid function models: a – plot fit of P_{max} with T_0; b – curve fit; c – Plot fit on P_{max} with $F(5)_{warp}$; d – curve fit

From the curve estimations, the curve function models can be selected as the best degree of fitting. As for the knitting material pressure values, at the initial stage, with the increase of x, the growth rate of y (P) gradually increased, and the curve showed a trend of rapid increase; in the medium term, although x

is in the growth stage, the growth of y (P) is relatively slow, and the curve shows a more gentle rise when the inflection point (x, y) is reached, because the saturation degree of function reached the end, with the increase of x and y increased slowly, the pressure growth rate approached zero, and the curve developed horizontally [21]. We used adjusted R-Square to define the degree of fitting, the adjusted R-Square less than R-Square and R, chose the good adjusted R-Square and lowest standard error of the estimated value.

(1) The sigmoid function (natural exponential function) models which are composed of KES parameters in the warp direction and non-directional (T_0, T_M) have been established. In mathematical terms, these kinds are equations with the limit range of $P_{\max}$ values (Appendix IV, Table IV.6). Moreover, we used the method of stepwise analyzed $P_{\max}$ with $F(5...E_{\max})$ and material properties from KES, then obtained multivariable linear equation (4.7) below in warp direction, ANOVA on F-test $sig. < 0.000$, coefficients on t-test $sig. < 0.01$ and Pearson correlation coefficient R is 0.9999, the coefficient of determination of R-square is 0.9998 and adjusted R-Square is 0.9995, these selected equations have the goodness of fit.

Equations: R^2_{adj}:

$$P_{\max} = e^{\left(2.709 - \frac{1.853}{T_0}\right)}, \quad 0.595 \qquad (4.4)$$

$$P_{\max} = e^{\left(2.334 - \frac{1.028}{T_M}\right)}, \quad 0.541 \qquad (4.5)$$

$$P_{\max} = e^{\left(0.721 - \frac{2.924}{F(8)_{\mathrm{warp}}}\right)}, \quad 0.536 \qquad (4.6)$$

$$P_{\max} = 2.417 \cdot T_M + 5.159 \cdot T_0 - 0.181 \cdot F(5)_{\mathrm{warp}} + 0.127 \cdot F(8)_{\mathrm{warp}} - 0.031 \cdot F(11)_{\mathrm{warp}} - 0.014 \cdot EMT_{\mathrm{warp}} - 24.964 \cdot LC + 5.709, \quad 0.999 \qquad (4.7)$$

where e is the natural base approx. 2.718; T_0 and T_M are KES parameters; $P_{\max}$ is the maximum pressure value, the equations of (4.4) and (4.5) can derive the pressure range during $0 < P_{max} < 15.01$ kPa, (4.6) only can derive the pressure range from $0 < P_{max} < 2.056$ kPa, (4.7).

Then, the sigmoid function (natural exponential function) models which are composed of KES parameters in weft direction have been established. And the equation (4.11), ANOVA on *F*-test *sig*. < 0.05, coefficients on *t*-test *sig*. < 0.05 and Pearson correlation coefficient *R* is 0.9999, the coefficient of determination of *R*-square is 0.9999 and adjusted *R*-Square is 0.9992.

Equations: R^2_{adj}:

$$P_{max} = e^{\left(0.765 - \frac{3.886}{F(11)_{weft}}\right)}, \quad 0.804 \quad (4.8)$$

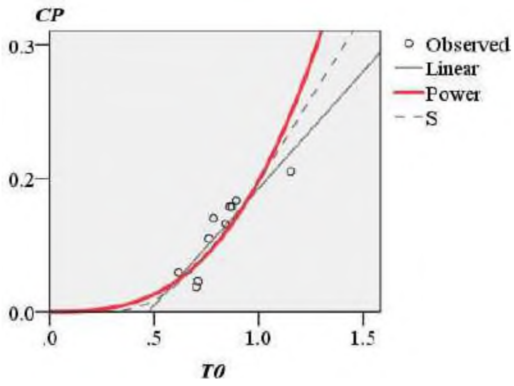
$$P_{max} = e^{\left(0.743 - \frac{7.852}{F(20)_{weft}}\right)}, \quad 0.820 \quad (4.9)$$

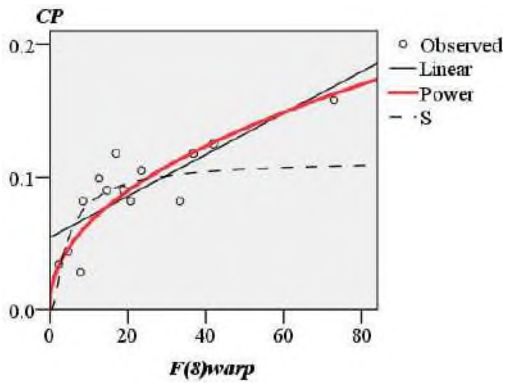
$$P_{max} = e^{\left(0.75 - \frac{7.404}{F(E_{max})_{weft}}\right)}, \quad 0.829 \quad (4.10)$$

$$P_{max} = 0.662 \cdot F(5)_{weft} - 0.446 \cdot F(8)_{weft} + 0.162 \cdot F(11)_{weft} + 0.101 \cdot F(17)_{weft} - 0.153 \cdot F(E_{max})_{weft} + 15.983 \cdot T_0 - 23.497 \cdot T_M - 0.019 \cdot EMT_{weft} + 2.99 \quad 0.999 \quad (4.11)$$

where *e* is the natural base approx. 2.718; $F(5 \ldots E_{max})$ are KES parameters tensile force, gf/cm, P_{max} is the maximum pressure value, the equations of (4.8) to (4.10) can derive the reasonable pressure range during $0 < P_{max} < 2.132$ kPa, equation (4.11) in mathematical terms, without limit range of P_{max} values.

(2) We calculated equations that have the best fit (Figure 4.25), for warp and weft of *CP* and E_{max} with low error ε.





a b

Figure 4.25 – Plot of fit curves: a – power-curve; b – power-curve

Equations: R^2_{adj}:

$$CP = 0.148 \cdot T_0^{2.907}, \quad 0.635 \quad (4.12)$$

$$CP = e^{\left(-1.689 - \frac{1.704}{\mathrm{SMD_{warp}}}\right)}, \quad 0.805 \quad (4.13)$$

$$CP = 0.022 \cdot F(8)_{\mathrm{warp}}^{0.463}, \quad 0.672 \quad (4.14)$$

$$CP = 0.017 \cdot F(20)_{\mathrm{weft}}^{0.398}, \quad 0.746 \quad (4.15)$$

where e is the natural base approx. 2.718; $0 < F(8)_{\mathrm{warp}}$, $F(20)_{\mathrm{weft}} < 200$ gf/cm (is average of maximum tensile force value for underwear material); CP is the pressure performance ratio, $0 < CP \leq 1$, kPa/%; $T_0 < 1.5$ mm.

(3) Moreover, we analyzed equations which have the best fit, and bring in the actual values to choose the best function curves (Figure 4.26).

Equations: R^2_{adj}:

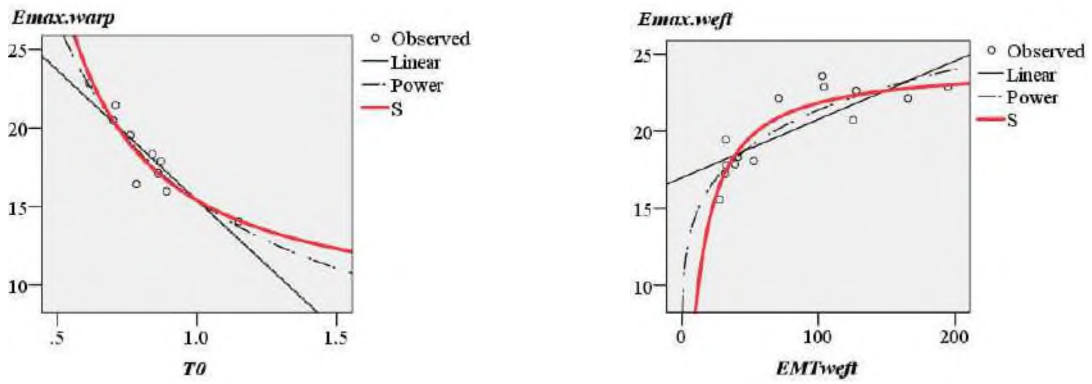
$$E_{\mathrm{max.warp}} = e^{\left(2.068 + \frac{0.666}{T_0}\right)}, \quad 0.852 \quad (4.16)$$

$$E_{\mathrm{max.warp}} = 0.025 \cdot EMT_{\mathrm{warp}} - 0.073 \cdot F(8)_{\mathrm{warp}} + 18.781, \quad 0.843 \quad (4.17)$$

$$E_{\mathrm{max.weft}} = e^{\left(3.191 - \frac{10.789}{EMT_{\mathrm{weft}}}\right)}, \quad 0.794 \quad (4.18)$$

$$E_{\text{max.weft}} = 0.025 \cdot EMT_{\text{weft}} - 7.131 \cdot T_0 + 23.118, \qquad 0.888 \quad (4.19)$$

where e is the natural base approx. 2.718; EMT is elongation at 500 cN / cm load, %; $0 < E_{\max}$, %.



a b

Figure 4.26 – Plot of fit curves: a – S-curve; b – power-curve

Through these equations, the pressure ability of knitted material, and the elongation $E_{\max}$ in underwear pattern block and ease allowance can be predicted by knitted material’ properties parameters.

4.7. Check mathematical models

We knew the type variables have high correlations, and good R^2 from equations (4.4) to (4.19), but still want to determine the error δ in equations. The calculation data from the knitted material samples are based on all equations, so we use the original data and then bring it into the equation for test calculation.

$$\delta = \triangle / y \cdot 100\% \qquad (4.20)$$

where δ is actual relative error, %; $\triangle$ is the absolute error, predicted value $\hat{P}$ ($\widehat{CP}$, $\hat{E}$) minus true (measured) value P (CP, E); y is true (measured) value P (CP, E).

Test results are shown in Table 4.9 (Appendix IV. Table IV.7 and 8). And the second quartile Q_2 (Percentiles 50) is the median of δ, δ and Q_2 of δ close to

0% are the best results.

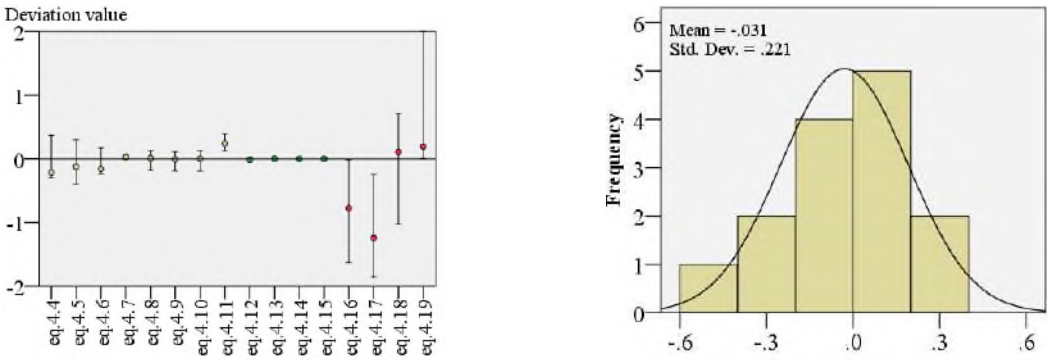
We also take account others into the tests – Kurtosis and Skewness, Kurtosis – peakedness, positive kurtosis indicates heavy tails and peakedness relative to the normal distribution, whereas negative kurtosis indicates light tails and flatness [36]. The positive kurtosis means that predicted values close to 0 value center they have a wider range, the negative kurtosis dispersed from 0 value center means they have a narrower range, to some extent, the positive is better than negative kurtosis. So, we need to check the Skewness – negative skew, the left tail is longer, the mass of the distribution is concentrated on the right of the figure; positive skew, the right tail is longer, the mass of the distribution is concentrated on the left of the figure [35].

As showed in Table 4.9, the first or second good values are marked in bold. Due to equations for different kinds of values prediction, the different tolerance level of $\varDelta$ and δ have.

Table 4.9 – Mean result of recalculated equations

Equations of $\hat{P}$	$\varDelta$, kPa	δ, %	S.D., ±	Variance	Kurtosis	Skewness
(4.7)	-0.030	2.27	**0.020**	0.134	4.096	1.736
(4.8)	**-0.021**	**-0.72**	0.227	0.051	-0.349	-0.399
(4.9)	-0.031	1.77	0.221	**0.049**	-0.005	-0.304
(4.10)	**-0.020**	**-0.80**	0.216	**0.047**	-0.652	-0.088
Equations of $\widehat{CP}$	$\varDelta$, kPa/%	δ, %	S.D., ±	Variance	Kurtosis	Skewness
(4.12)	**-0.0016**	5.94	0.029	0.001	1.938	1.482
(4.13)	**-0.0016**	2.99	0.027	0.001	1.195	0.246
(4.15)	**-0.0016**	**2.87**	0.021	**0.000**	0.72	0.641
Equations of $\hat{E}$	$\varDelta$, %	δ, %	S.D., ±	Variance	Kurtosis	Skewness
(4.16)	-0.652	-3.38	1.450	2.103	2.217	1.079

(4.18)	**-0.034**	**0.14**	**1.151**	**1.325**	-0.595	-0.232



a b

Figure 4.27 – a – Diagram of quartile: unite of (4.4) to (4.11) is kPa, unite of (4.12) to (4.15) is kPa/%, unite of (4.16) to (4.19) is %; b – histogram of equation (4.9)

The equations (and second choose) are as shown in Table 4.9.

for P_{max} (4.10) with an error of ± 0.216, and additional (4.7) with an error of ± 0.020, (4.8) with an error of ± 0.227, (4.9) with an error of ± 0.221;

for *CP* – on the warp of (4.13) with an error of ± 0.027, on a duck (4.15) with an error of ± 0.021;

for $E_{max.warp}$ – (4.16) with an error of ± 1.450;

for $E_{max.weft}$ – (4.18) with an error of ± 1.151.

The obtained equations can be used for the design of compression knitted kinds of men's underwear. Firstly, we measure the tensile force *F* of a sample of knitted material to elongate it by average 19%, calculate the allowable value of compression pressure of the knitted shell on a particular part of the figure, and then check the sufficiency of the size for the designed parts.

For example, the following values of the negative ease are recommended in the parts of the body, %.

Upper arm	Lower arm	Waist	Waistband	Hip	Thigh	Calf	*Mean*
-19.11	-17.86	-19.05	-20.42	-23.09	-17.92	-18.92	*-19.48*

Summary of chapter 4

On the basis of complex testing of 14 knitted materials in different conditions and with the use of different methods and means of research, the following conclusions were obtained:

1. The correction intervals for plastic male bodies and the values of the push-up effect are set: front 2.8...4.5 cm, back 1.8...2.0 cm.

2. The average maximum E_{max} is from 14.8 to 22.2%; it is the critical value of the maximum acceptable elongation range for the testee. Through the real body pressure sensitivity test, the maximum P_{body} is between 1.21…1.86 ± 0.58 kPa.

3. The possible pressure for different body parts have been established after experiments. The following ranking of the soft tissues sensitivity has been established under compression pressure P_{body}: *hip* < *thigh* < *natural waist* < *calf* < *waistband* < *forearm* < *upper arm*.

4. An algorithm has been developed for calculating constructive ease for designing underwear, based on data related to materials and the sensitivity of soft skin tissues of male bodies to compression pressure.

5. A new indicator has been proposed for determining the compressive capacity of materials, calculated from the results of measuring the tensile stress of samples for certain values and pressures in a real "body-shell" system. The capabilities of the KES-FB-1 device were used to obtain such stretching index that correspond to the operating conditions of the underwear.

6. A comparison of the developed index of compression performance with a known index was made and its advantages for predicting pressure were shown: a decrease in the prediction error from 28.3% (0.665 kPa) to 20.14% (0.260 kPa).

7. Equations were obtained for calculating the maximum compression pressure under tight-fitting knitted shells, the compressive performance index

and the maximum elongation of the materials necessary for the development of underwear drawings.

Chapter 5. DEVELOPMENT OF NEW METHOD FOR DESIGNING MEN'S UNDERWEAR

We analyzed the relationship between pants and underwear prototypes in the lower part of the male body. Figure 5.1 shows the real skin and dummy skin we made (Figure 5.1 c, d) fit closely with the human body, and then according to the front and back centerline and sideline of the lower part, the mannequin skin is stripped off. Compared with Figure 5.1 a, b, it can be seen that the structures are the same. In theory, this block can fully fit with the lower torso surface, this part of skin blocks is the structurally perfect condition of men’s underwear. But due to the performance constraints of the different underwear knitted material, the pattern block need to be modified to adapt to the knitted material properties.

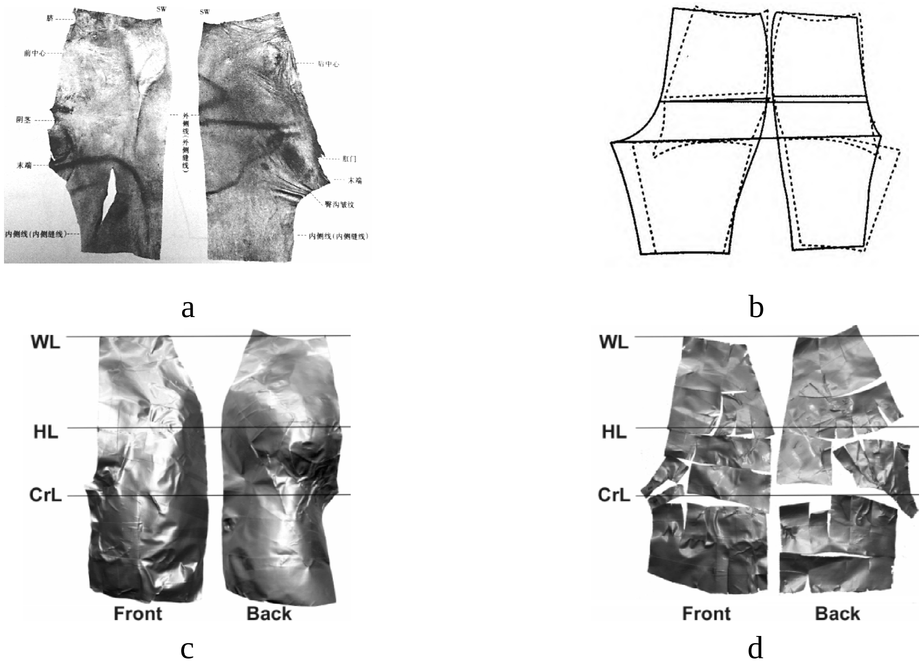
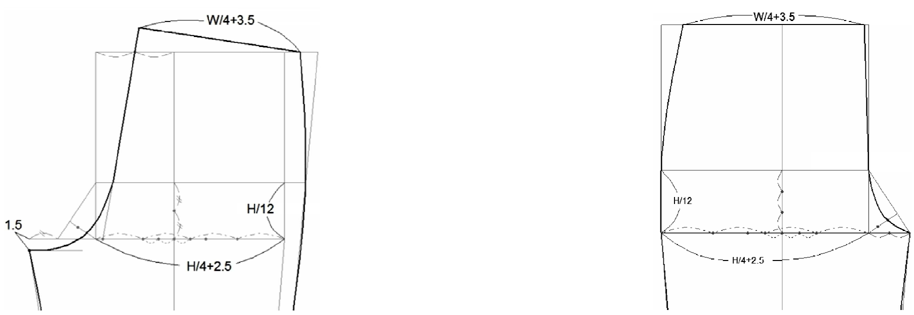


Figure 5.1 – Male lower limbs skin spread: a – real male skin, b – comparison of skin and pants pattern block, c – original pieces, d – cracked pieces

After unfolding the front and back parts of body “skin” to compare the gaps/cracks, we can see that the cracking degree in the back piece is significantly greater than the front piece, and many cracks are at the hips (gluteus) and groin. The “skin” cracks converge on the crotch line (*CrL*) and hip line, while the upper part is similar to a tight-fitting underwear pattern block (Figure 5.1d). The structure of underwear is to fit the human lower torso so that we can refer to the theory of men’s tight-fitting pants to analyze the men’s underwear.

5.1. Feature of the design of pants and underwear

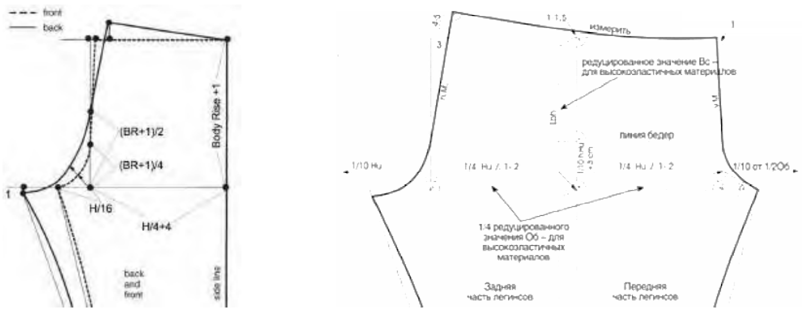
Because of the structural commonality, the short-sleeved vest can be drawn by a top prototype, in shorts, underwear can also be improved by tight-fitting pants prototype drawing. We taking the men’s pants prototype in China’s teaching book as an example, the pattern is divided into four pieces (Figure 5.2). It is characterized by the H_G as the basic parameters, to calculate the proportion of the data of each body part, hip width = H_G / 4 + ease, the distance between hip and crotch level is $\Delta = H_G / 12$. In totally, the width of crotch peaks extends at crotch level on patterns front and back is taken the typical value “$0.145 \cdot H_G$ to $0.16 \cdot H_G$”, as for front is “$H_G / 18 = 2/3 \cdot \Delta$”, the back is “front width + $1/2 \cdot \Delta$”.



a b

Figure 5.2 – Two pieces type men’s BPB: a – back, b – front

We also take the men’s pants prototype in the European teaching book as an example. The pattern is divided into two pieces (Figure 5.3), it is characterized by the H_G as the basic parameters in the horizontal direction, and body rises (*BR*) as a basic parameter in the vertical direction to calculate the proportion. Similarly, the pattern drawing method in Figure 5.3a shows "hip width = H_G / 4 + ease", the width of crotch peaks "***1***" extend at crotch level on patterns front and back, front is "H_G / 16", the back is "front width + 1/2 · (H_G / 16 + 0.5)". Figure 5.3b shows the back crotch extends "H_G / 10".



a b

Figure 5.3 – Men's one-piece pants BPB: a – two-pieces; b – one-piece

Pants prototype crotch width distribution. Due to different body size, the pants size in different countries, regions, and the equation to calculate the pants' crotch width in pattern block are not the same. According to the results of the 1997 human body census in China, the reasonable value for the fit style pants – crotch width is about "0.16 · H_G", crotch width in front is "0.05 · H_G" or "0.07 · H_G", back is "0.11 · H_G" or "0.09 · H_G", and the sum is "0.16 · H_G".

- The first group distribution value is "0.05 · H_G + 0.11 · H_G = 0.16 · H_G".
- The second group distribution value is "0.07 · H_G + 0.09 · H_G = 0.16 · H_G" [269, pp.103-125], [210].

In Europe, the typical crotch width – "0.0625 · H_G + 0.125 · H_G = 0.19 · H_G" [18, pp.255-258], [44, pp.88-89]. But, as for tight-fitting is "0.145 · H_G", the common type is "0.15 · H_G", and front crotch is 3…4 cm [246, pp.151-162].

Comparison of boxers and pants structure. To explore and validate the regularity in common patterns, we have analyzed a large number of pants, shorts and boxers patterns with or without side seams. To compare the pants basic pattern block BPB and underwear BPB, we drew out both blocks in according with the guidelines of the front, back center, and hip level as shown in Figure 5.4.

a b

Figure 5.4 – Comparison of underwear and pants BPB: a – back; b – front

From the comparison, take the front and back center and hip line as a reference line to overlap in Figure 5.4 a. It just has a significant difference in the specific angle, and the underwear back center line(the upper part of the hip line) has not tilt as pants, because the back center line needs to extend and tilt to make the knitted material meet the human buttocks and curved potential. The position of underwear back crotch peak are deleted 0.5…1.5 cm (the amount of pants crotch peak downward value). As shown in Figure 5.4 b, the structure and proportion of underwear and pants are different. The front crotch peak is upper about 3…4 cm from crotch level, and is roughly at the 1/2 between hip and crotch level, which makes the bottom of front insert piece closely to the body crotch part for holding the male genitals.

As showed in Figure 5.5, we overlapped pants and underwear prototypes based on hip line, the pants and underwear structures are divided into left and right two pieces without side seam. From the comparison, we can see the same outline of the back center lines and the curves. But underwear front center curve angle is more tilt than pants. Underwear back crotch peak level is upper 1…2

cm than pants, the front crotch peak level is upper 3…4 cm and is roughly at the 1/2 part of hip line to the crotch level.

For example, the five men’s underwear are overlapped (Figure 5.6) with the same size, and taking the hip line and side seam as reference. Through comparison, the overall structure of these five Boxers changed a little while drawing in different ways. Only a little difference exists in the front center curves, and the front crotch peak point is higher about 1…4 cm than the back point.

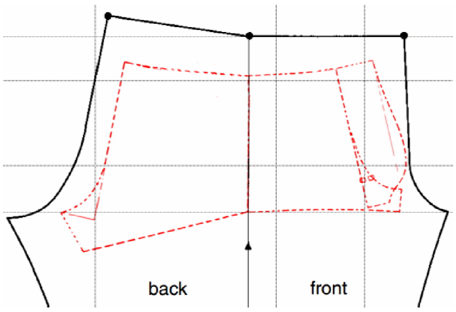


Figure 5.5 – Men’s one piece pants and underwear BPB

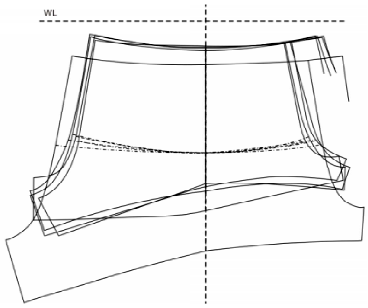


Figure 5.6 – Overlapping of men’s underwear pattern blocks

According to the pattern blocks comparison, a few differences between basic pattern blocks can be seen: (1) The horizontal crotch level of men’s underwear is higher than the pants. (2) The level of back crotch peak point of underwear is about 1 cm higher than the pants. (3) The level of front crotch peak point of underwear is about 3…4 cm higher than the pants. (4) The waist (waistband) level of underwear position is shorter and lower than the pants. (5) The crotch widths are as follows: the pants is about $0.15 \cdot H_G$, and underwear is less than $0.1 \cdot H_G$. Because of the similar methods of pattern making between these kinds of clothes, we chose the basic pants pattern block to develop the method of men’s underwear design with different functional effects.

As for the design of waistband, the existing drawing methods are based on the waistband size of finished underwear with production experience data. The waistband of underwear is usually 63…68 cm (for the middle size body), the position is below the natural waistline 4…20 cm, usually is 4…10 cm.

E.g. the waist length for underwear design from teaching books

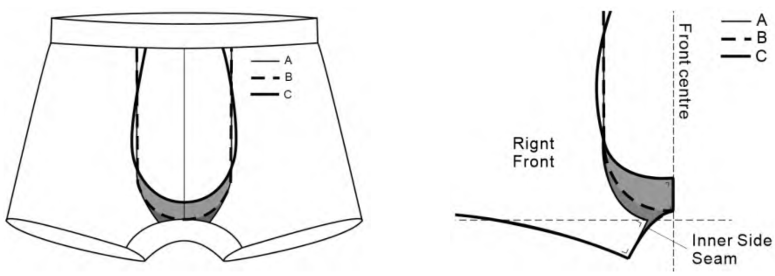
$$WB_{L} = (H_G^{*} + 2...4) \cdot (10 / \Delta E) \quad (5.1)$$

where WB_L is the waistband length for underwear pattern block; H_G^{*} is hip girth without ease; 10 is knitted material original length (10 cm); ΔE is knitted material after stretched from 10 cm to a reasonable range. E.g., H_G^{*} = 90 cm, a = 15 cm, WB_L is (90 + 2…4) · (10 / 15) = 61…63 cm.

$$WB_{L} = Mid\text{-}W_{G} \cdot (1 + E) \quad (5.2)$$

where E is elongation, %; $Mid\text{-}W_G$ at the level of natural waist 8 cm below. E.g., $Mid\text{-}W_G$ = 84 cm, b = 25%, WB_L = 67cm.

The Figure 5.7 shows three variations of underwear – A, B, C design methods of the front insert. To design the volume of front insert to maintain and form the male genitals, the length of the front insert is aligned with its width. Figure 5.7 shows three variants: A – the traditional type, without the push-up effect, it has the longest and narrowest width, the front insert bottom is sewed with inseam; B – a type with moderate push-up effect, it has a narrow width and curving front insert bottom; C – a type with a stronger push-up effect, it has a short length and oval-shaped front insert.



a b

Figure 5.7 – Variants of the front insert shapes: a – front, b – the configuration of the insertion line for the inserts to front

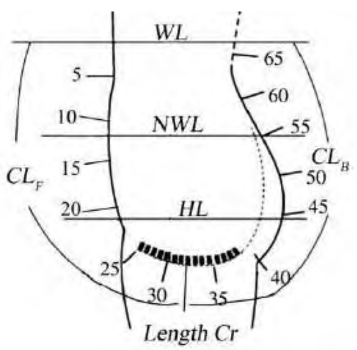


Figure 5.8 – Length scale at crotch area [229]

The Figure 5.8 shows the example of crotch length CL of small size body (Yin Jianrong, 2007, pp.135) [229], the front (CL_F) and back (CL_B) length are illustrated, and the design length at the crotch bottom is illustrated. The full crotch length of high-waist underwear is more than 55 cm; the mid-waist is 45…55 cm; the low-waist is 35…45 cm, and the length of crotch part in common is more than 13.5 cm (Figure 5.8). But, the volume of the male genitalia is not described.

The possibilities of mentioned methods do not allow designing the contemporary underwear. In Chinese teaching books, they just use the girth of the waist as the variable value at belt part and use the unclear methods and constant values in pattern making for other parts. Many empirical values cannot be used in varieties of underwear.

5.2. Development of a new method for designing underwear

5.2.1. Basic construction

The algorithms for men's underwear design (trunks, boxers *etc*.) are based on the following initial data: body sizes; the reference lines are the same as pants drawing *etc*.

Firstly, N_{WG} – new waist girth as waistband is located below natural waist level; *CL* – the full crotch length from *WF* through *Cr* to *WB* (very close to body); NT_G – new thigh girth as underwear bottom in horizontal and slope directions; $\Delta F = CLF\text{-}BR$ – the value describing genitals bulge; $\Delta B = CLB\text{-}BR$ – the value describing hip (buttocks) bulge; *BR* – distance of the body rise; h_W – the distance between the nature waistline height and the height of the new waistband (to describe the height of underwear belt design), this distance are 4…10 cm.

Next, we have designed a typical basic pattern block of men's underwear – "Boxers I", as shown in Figure 5.9. The main algorithms include the following steps [296-302]:

- Draw the structure and anthropometric lines based on the upper of basic pattern block – waistline, hipline, crotch line, thigh etc.

- Define the possible combinations of the two variables “values of material extensibility (ease *E*) - compression pressure (*P*)” as shown in chapter 4. To ensure these two variables balanced.
- Select the desired values of push-up effect (for the anterior and posterior separately) and the solution of how to achieve them. By structure design due to design in front insert piece (independent front insert piece, design the special insert like a pouch).
- Draw the back piece (the design of less divided back piece usually includes front and side).
- Draw the front insert piece.
- Draw the crotch piece (designed).

5.2.2. The basic design of Boxers type I

The details of the algorithm and drawing method for a basic type “Boxers I” is shown in Figure 5.10 (and Appendix V, Table V.1).

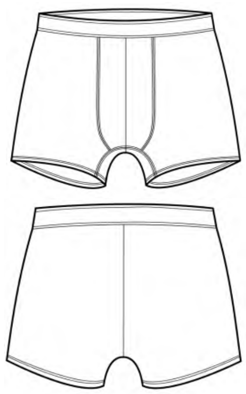


Figure 5.9 – Men’s underwear basic type

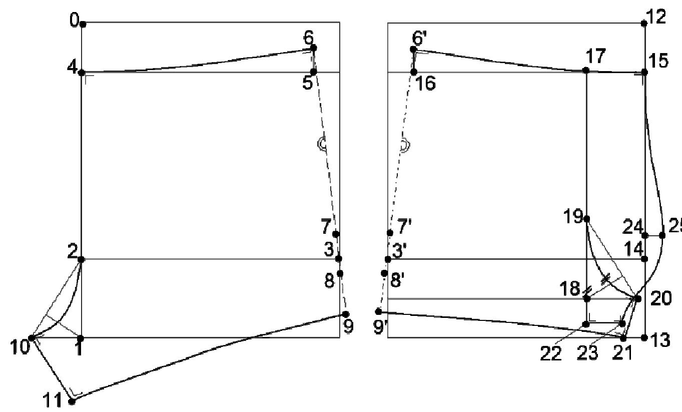


Figure 5.10 – The algorithm for constructing the BPB of underwear, right is front with insert, left is back

If it is based on *S, M, L* size of our classifications to draw a basic pattern block, we recommend two ways for grading. Firstly, “*Method No.1*” as shown in

Figure 5.11. The grading values calculations are based on their differences from our body measurements database, the order is arranged from small to large, each group of data is calculated separately, then, the differences between each group of data are calculated (Table 5.1).

In vertical, the differences of full *CrL* and *BR* grade are 4.6 (1/2 is 2.3 cm) and 2.0 cm separately, we took the smaller scale ± 2.0 cm for waistband part vertical grading. In horizontal, the NW_G difference is 5.76 (1/4 is 1.44 cm) cm, we take 1/4 front piece change ± 1.4 cm in horizontal, grading direction is to the side, and front insert doesn't change; back change ± 0.7 cm in both side (Figure 5.11). In crotch part, *ΔWH* is influenced by the value of ***/1-10/***, the average difference of *ΔWH* is 1.46 cm, we take ± 0.7 cm in back crotch part for grading. As for NT_G below crotch level (-10 cm lower from *CrL* level) for grading, the bottom curve is change ± 0.9 cm in front, grading direction following the bottom curve. Change ± 0.45 cm in the back of both sides.

Table 5.1 – The algorithm of detail parts for average sizes, cm

Measurements	Vertical		Horizontal			
	CL	*BR*	*ΔWH*	NW_G	NT_G *decline*	*ΔGW*
Difference, ±	4.60	2.04	1.46	5.76	1.71	0.86
Front	2.3	2.0	*Not change*	1.4	0.9	–
Back	2.3	2.0	0.7	0.7/0.7	0.45/0.45	–
Insert	2.3	2.0	–	*Not change*	–	0.5

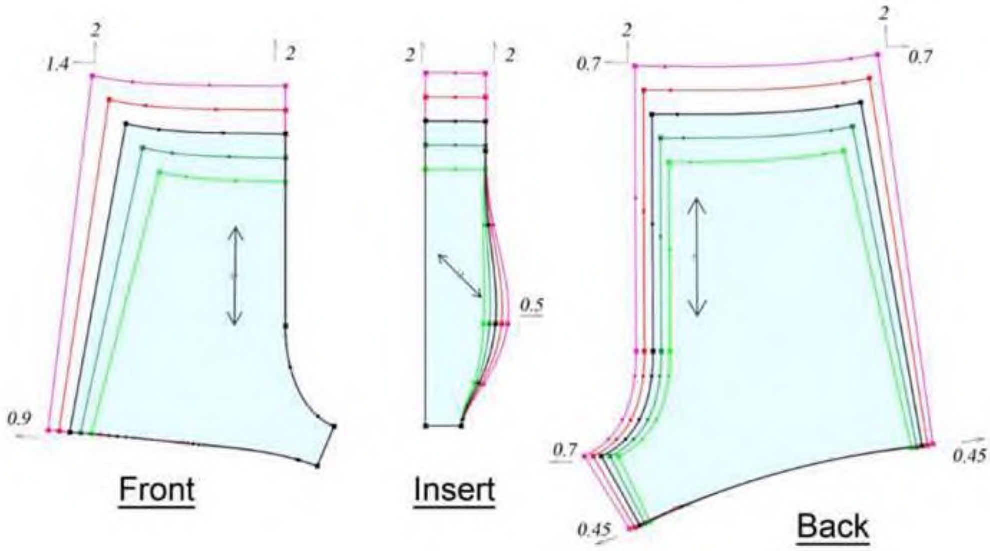


Figure 5.11 – Underwear grading "Method No.1"

Table 5.2 – "Method No.2" and value for the basic men's underwear products based on new classification, cm

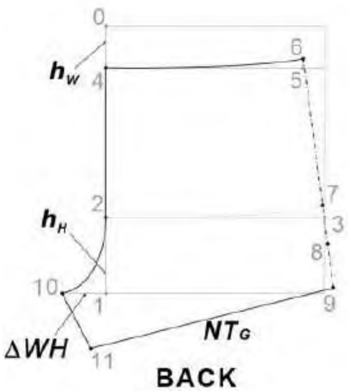
	Samll				Middle				Large			
Main	***S***				***M***				***L***			
Range of H_G	< 92				92…98				> 98			
$\underline{H_G}$	*91*				*95*				*98*			
Main	S^-	S	S^+	S^{++*}	M^-	M	M^+	M^{++}	L^-	L	L^+	L^{++}
Range of W_G	< 71	71... 84	84... 98	> 98	< 71	71... 84	84... 98	> 98	< 71	71... 84	84... 98	> 98
$\underline{W_G}$	*70*	*73.5*	*84*	*91*	*74*	*77.5*	*88*	*99*	*77*	*80.5*	*91*	*102*
Sub.	***/SS***				***/MM***				***/LL***			
ΔGW	0…0.5				0.6…1.5				1.6…3			
ΔWH	2.6				4.1				5.6			
Recommendations												
BR^*	29.7				31.5				32.7			
h_H	$0.25 \cdot BR^*$ - 1= 6.43				$0.25 \cdot BR^*$ = 7.88				$0.25 \cdot BR^*$ + 1 = 9.18			
h_W	0…20, (design value)											

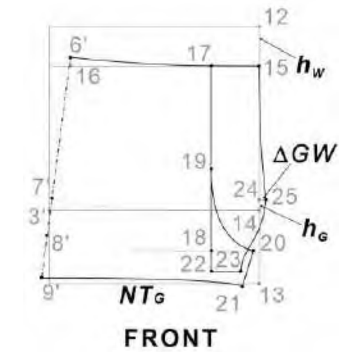
h_G	0…9, (design value, average is 3.5)
NW_G, ($< H_G$)	$NW_G = 0.02 \cdot h_W{}^2 + 0.61 \cdot h_W - 0.55 + W_G$
"<u>**H_G**, **W_G**</u>" with the underline, take our mean results as recommendations. "**S^{++*}**" special size, as for *S* size girth of waist usually less than the hip in practice. "**BR^***" is the value/size in structural drawing, calculated by body's BR, define the underwear products size.	

Secondly, we have created the "*Method No.2*" as shown in Table 5.2. The "*Method No.2*" is a new size chart with critical values for men's basic underwear based on our new classification. This method which we added more design details than the first method is also suitable for mass production.

As shown in Table 5.3, the example of our "*Method No.2*" is applied to the basic pattern block.

Table 5.3 – Method No.2 for basic underwear

<table>
<tr><th>Pattern blocks</th><th>Measurements</th><th>Correspond sizes</th><th>Type</th><th>Average values, cm</th></tr>
<tr><td rowspan="5">
</td><td>Length /0-4/ = /12-15/</td><td>h_W, NW_G below W_G</td><td>S, M, L</td><td>Design value</td></tr>
<tr><td>Length /1-2/ = /13-14/</td><td>According to h_H, H_G above CrL</td><td>S
M
L</td><td>$0.25 \cdot BR - 1$;
$0.25 \cdot BR$;
$0.25 \cdot BR + 1$</td></tr>
<tr><td>Curve /4-6/ = /6'-15/</td><td>NW_G, in Table 2</td><td>S, M, L</td><td>Reference different h_W (add negative ease value)</td></tr>
<tr><td>Length /10-1/ = /20-18/</td><td>ΔWH, difference between the crotch back</td><td>S
M
L</td><td>2.6;
4.1;
5.6</td></tr>
<tr><td>Length /24-25/</td><td>ΔGW genitals bulge</td><td>S
M
L</td><td>0…0.5;
0.6…1.5;
1.6…3</td></tr>
</table>

	*Distance of /13-24/*	According to h_G	*S, M, L*	0…9 (mean is 3.5), or higher, Design value
	Curves /11-9/ + /9'-21/	According to NT_G	*S, M, L*	Reference different angles and h_T (add negative ease)

We can use a variety of combinations to design front and back, for different male shapes or the different desired feeling of dress. In totally, there are 12 main types of underwear can be used for design and production. If we design underwear with more details, such as ***S^+/SM***, ***M^-/ML***, ***L^+/SL*** *etc*. we need to add different values from the “sub. column”, and take *ΔGW* and *ΔWH* from three sizes. And then, take values from the “design column” for structural drawing.

For example, we make underwear with the 12 main sizes from S^-, *S*, S^+…L^{++}, we take average $\underline{\boldsymbol{H_G}}$ as 91, 95 and 98 cm; $\underline{\boldsymbol{W_G}}$ follows the “main column” 70, 73.5, 84 cm etc., and NW_G can be calculated. As for the mark “***/SS***, ***/MM***, ***/LL***” in the “sub. column” also means the small, middle and larger size, they are just used to describe the size of male body details in anterior and posterior. The sign “/” means the details size after the main size, we can write as ***S^+/SS***; but, if we designed *ΔGW* = 0.5 cm (small size ***/S***) and *ΔWH* = 6.0 cm (large size ***/L***) in underwear pattern, we need mark it as “***/SL***”, it means an underwear has a small front but large back.

5.2.3. The design of Boxers type II

This example shows how the design method is used in pattern block making of men’s underwear with different functions. New method and functionality type with push-up effect in front (a small insert, a separate crotch piece, we named it “Boxers II”). The application of the way for designing of boxers as type *C* we mentioned before with the insert in shortest length, most significant width, and significant crotch part. Such kind of structure (Figure 5.12) provides the maximum correction effect on body front.

The algorithm of boxers with the push-up effect is shown in appendix V, table V.1. The sample of underwear is shown in Figure 5.13. Male body (height 170 cm, waist girth 72 cm) used the following sizes: distance from waist to seat BR = 27.3 cm, new waist is below the nature waistline in h_W = 10.5 cm, the waistband width is 2.5 cm, hip girth H_G = 91.9 cm, thigh girth T_G = 56.6 cm, height from waist to floor in front D_{FL} = 87.6 cm, height from waist to floor inside D_{SL} = 88.7 cm, with the maximum E 19% in the experiment.

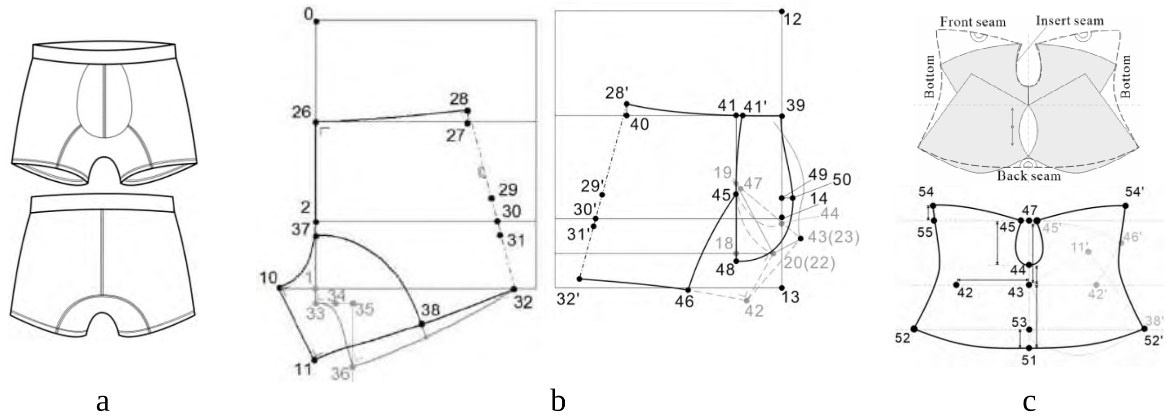


Figure 5.12 – Pattern block of Boxers II with crotch piece

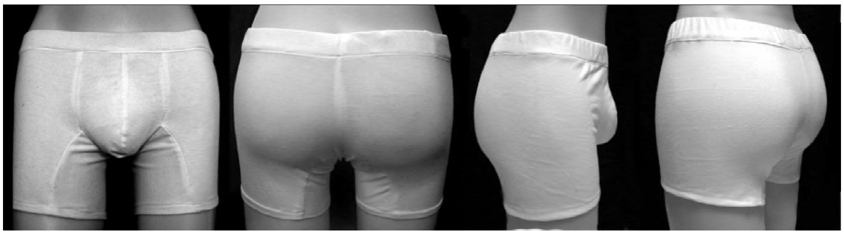
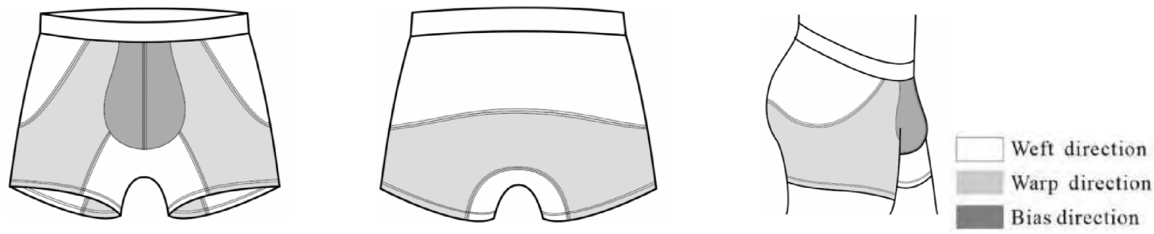


Figure 5.13 – Finished sample of Boxers II

In this example, the knitted material with a coefficient of extensibility *c* = 1.19, or in other words, with the possibility to decrease the girth (horizontal) value by (-19) %. We increase the length (vertical) value by (+5) % in this example because the vertical direction of materials shrinkage rate is 5% (in warp), and 9% (in weft).

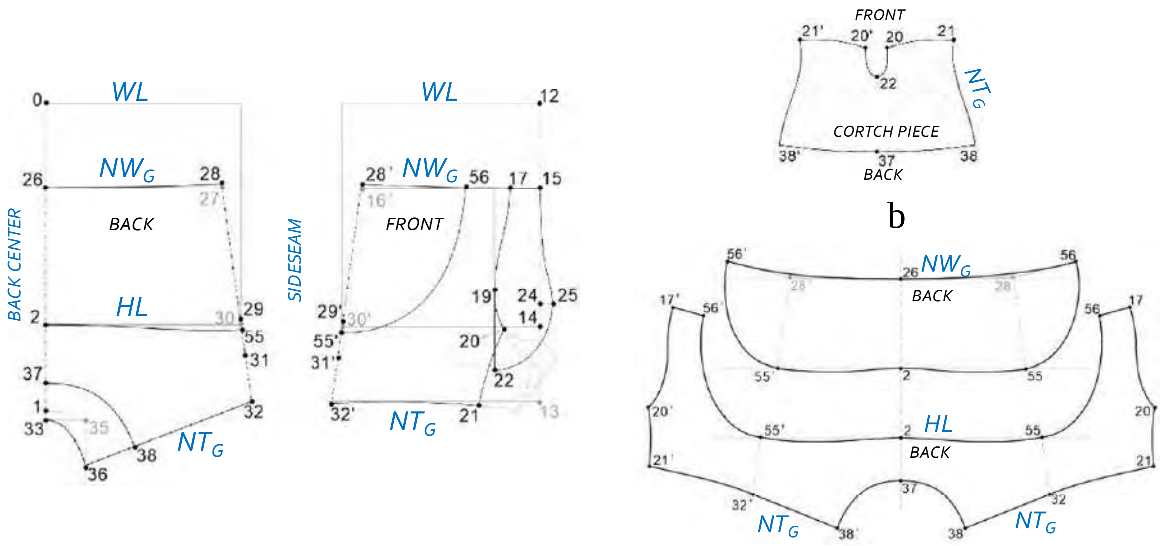
5.2.4. The design of Boxers type III

We designed a functional underwear with special seam from front to hips, this structural line across underwear back middle; in front, it has “pear” type insert, like “U” to make pouch lower and top close-fitting the front male genitals, and a large crotch piece. We also designed push-up effect in front and back, and a small front insert, a separate crotch piece with the new design method. These two “push-up” effects could make the male soft tissues lifting at front and back. The traditional front insert of male underwear usually used knitted material in warp or weft direction, but from our questionnaire before, we find that it has defects in wearing comfort.



a b c

Figure 5.14 – New design of underwear: a – front; b – back; c – profile



a c

Figure 5.15 – The algorithm for constructing the of Boxers III: a – front and back pieces; b – crotch piece; c – back structural pieces

So, in our design, as shown in the Figure 5.14, we take the bias direction for front insert and narrowed the top; make a structural arc line cross hip level to front on both sides of the insert part. We design the warp direction of knitted material at back lower and front thigh part as shown in grey color, it will provide an effect that is not easily deformed., this design also gives buttocks a good (tight) feeling of support and make the stability of the bottom line in outsides.

Four kinds of knitted materials are used for underwear making and comparing, take the body size ***M¯/SM***, the main method of drawing and crucial data are shown as the following:

0-26 10.5 cm

2-33 Equal to back crotch curve line on the basic prototype.

26-2 Shrinkage warp 11 · (1 - 0.055) = 11.6 cm, use the warp direction. The ease of elongation (in pattern horizontal) and shrinkage (in pattern vertical) for T_1, T_4, T_6 and T_{18} are 19% and 5%.

2-37 6 · (1 - 0.055) = 6.4 cm.

31-32 Designed value 4 cm.

28-55 Shrinkage warp 11.5 · (1 - 0.055) = 12.2 cm.

55-32 Shrinkage weft 5.6 · (1 - 0.055) = 5.9 cm.

33-36 Designed value 6.5 cm.

36-32 13 cm. ***/36-38/ =*** 5.5 cm.

15-17 3.5cm, the half width of the insert.

20-21 Draw a straight line from ***20*** to ***21*** and make a right angle at point ***20***.

21-38' Part of bottom line 14.5cm.

14-24 2 cm

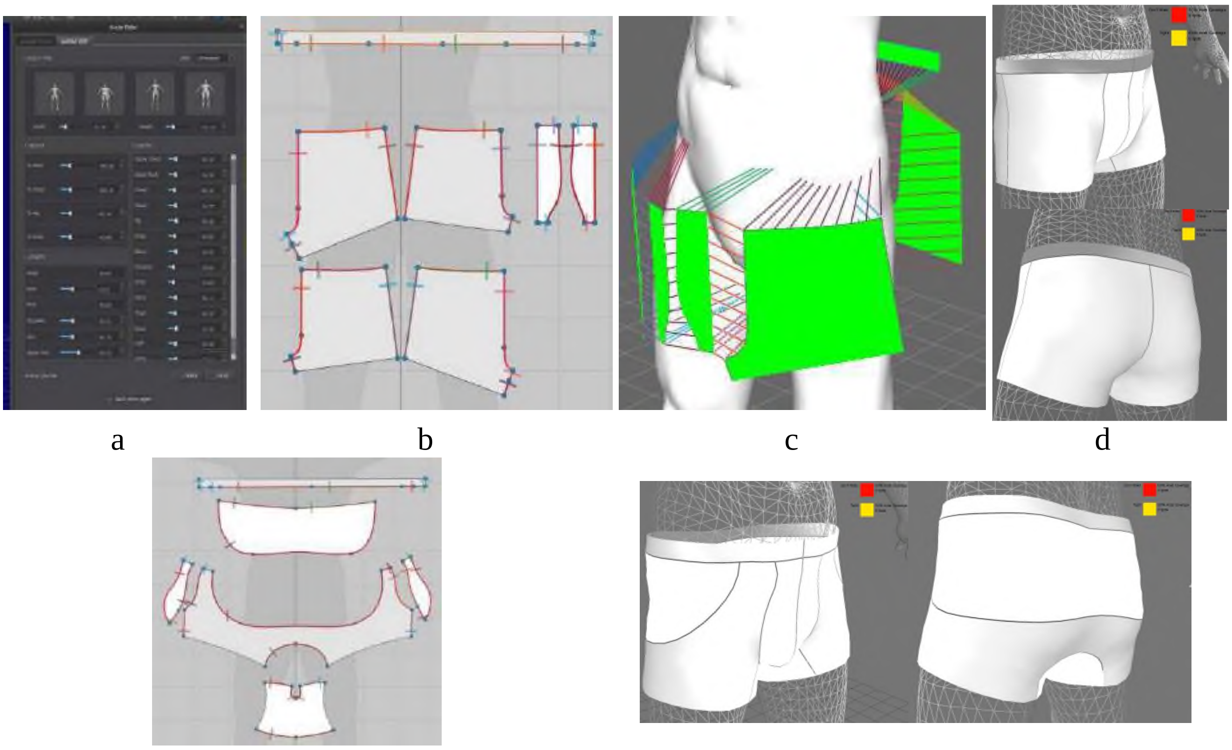
56-56' Draw a curve cross point ***26***.

5.3. Virtual system of “body-underwear”

5.3.1. Build a digital twin underwear

In the simulation experiment, we imported the human body scanning model to the software CLO, and modified crucial human dimensions according to model ***M⁻/SM***, as shown in Figure 5.16. The Figure 5.16b and d showed the 2D structure of Boxers I and Boxers III pattern blocks.

We can see that the underwear structure in Figure 5.16d, f, the red annotation means “cannot wear” – 0.0% area coverage 0 spots; “tight” – 0.0% area coverage 0 spots, our underwear finished model is all in white color, so this wearing performance of the structural drawing is right.



a b c d

e f

Figure 5.16 – 3D virtual simulation: a – body model size ***M⁻/SM***; b – pattern blocks (Boxers I); c – sewing process; d – Boxers I try-on; e – pattern blocks (Boxers III); f – Boxers III try-on

5.3.2. Development of digital twin for scanners

Figure 5.17 a shows 3 male profiles. We can see that the shapes of the profile are very different, even at the same size *M*. Then, we used the software of MakeHuman 1.1 (Figure 5.17 b) to establish *S*, *M*, *L* sizes virtual male bodies (size following Table 5.2). It can be clearly seen from the profiles that different waist sizes have different shapes on the part of abdomen and the back of the waist, when the hip girth is the same.

Figure 5.17 c are virtual models meets the average size of our classification, covers the genital area for lower torso of body. Finally, the “obj” human model file is imported into the CLO software for simulation.

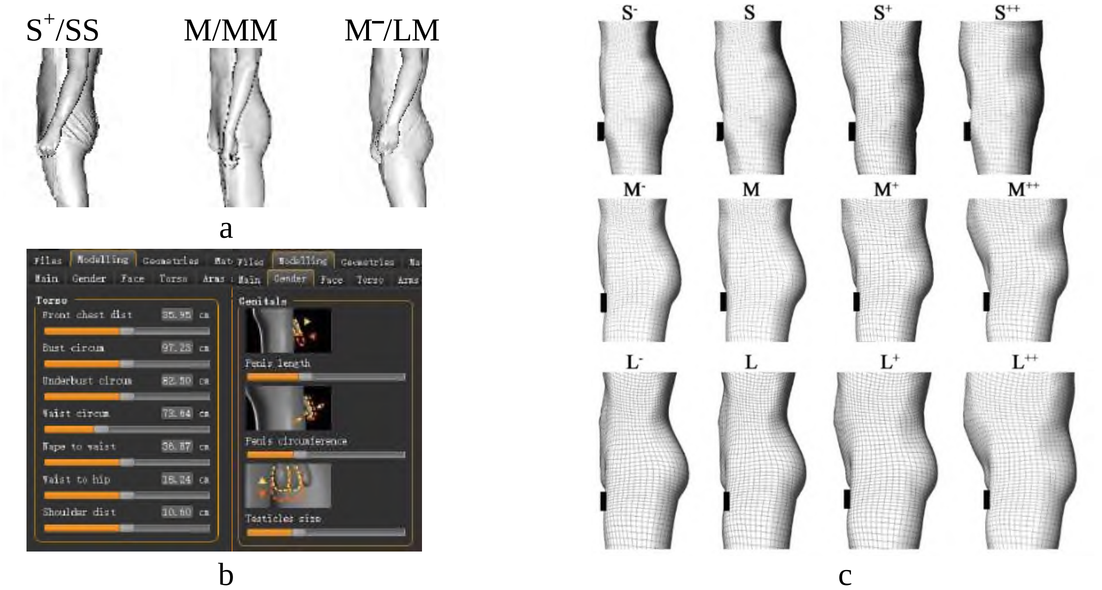


Figure 5.17 – 3D Human lower torso models: a – 3D scanning body; b – size modification; c – virtual body

5.3.3. The choice of digital twin knitted materials

CLO software is often used to simulate some loose, non-elastic clothing (coat, dress etc.) and commonly used knitted materials (cotton, silk etc.). But our design is mainly for tight underwear, its size will be smaller than the human body (smaller than the coverage area). Therefore, we need to consider the performance details of the elastic knitted material. We selected knitted materials parameters of physical properties into the CLO “Fabrics” option for simulation. Form the simulations of virtual knitted materials, we adjust the parameters and put the KES results into CLO. Such as the option “Detail”, the best way is to take the knitted material parameters G (shear stiffness), thickness and density into these 4 options of “stretch”, “shear”, “thickness” and “density”. After adjusting the properties of virtual knitted materials, we simulate the knitted material properties and measure pressure values (see Figure 5.18).

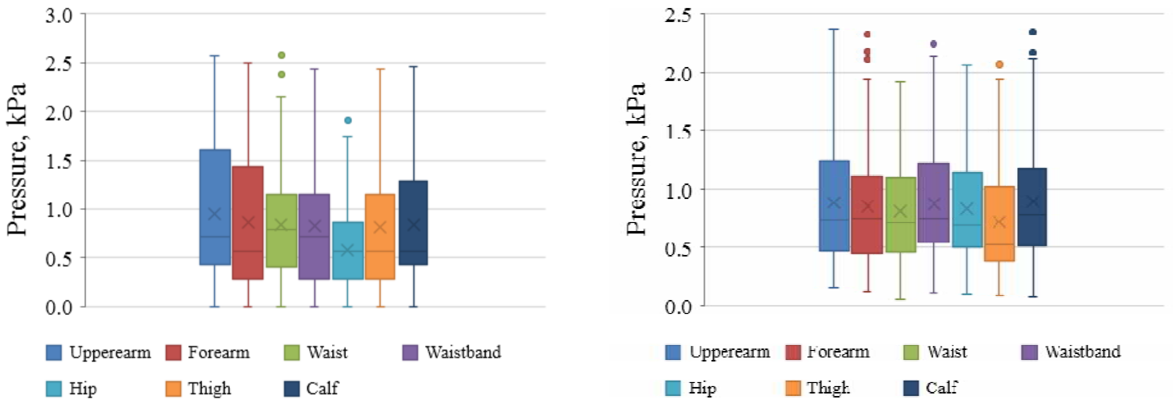
We have tested nearly 5000 virtual pressure value data PV in knitted materials two yarn directions on 7 parts of virtual body. The simulated virtual pressure (PV) is 0.14…2.13 kPa (real pressure on human body PB is 0.05…2.31

kPa) with knitted materials elongated from -20.0 to -5.0% in the warp and pressure is 0.00…2.82 kPa (PB is 0.13…2.02 kPa) in the weft direction.

a b

Figure 5.18 – Material simulation for virtual pressure test

As shown in Figure 5.19a, there are more zero pressure values and a wide distribution of the whole data in all the measured data on the human body.



a b

Figure 5.19 – Box diagram of pressure data: a – real pressure tested on male body; b – virtual pressure

As shown in Figure 5.20a, there are definite correlations between PB and PV of 14 knitted materials, which means that the connections between them and the simulated pressure are feasible, but the error needs to be corrected.

As shown in Figure 5.20b, we find that the knitted materials elongated from -15.0 to -10.0% with the largest difference from -0.26 to 0.24 kPa, and the lines intersect at -12.5%; in total, average error is ± 0.19 kPa. Then, we build virtual underwear and measure virtual pressure PV' from ease -20.0 to -5.0%, the result are as shown in Figure 5.20b.

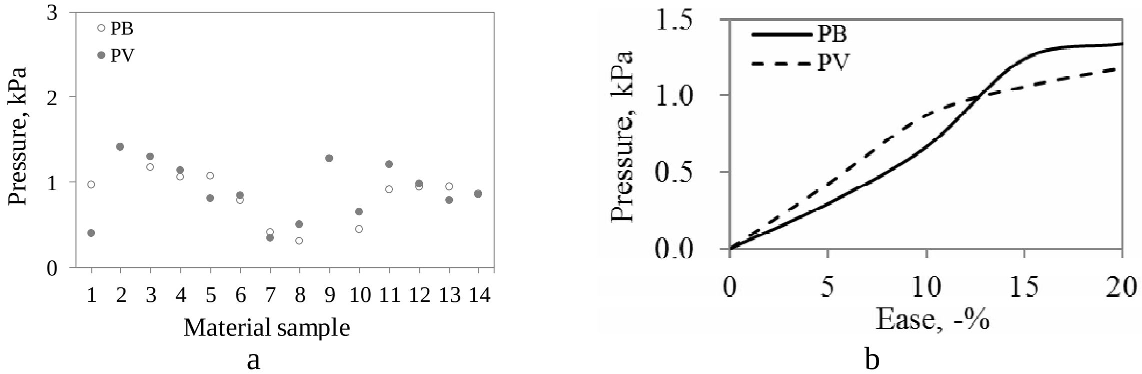
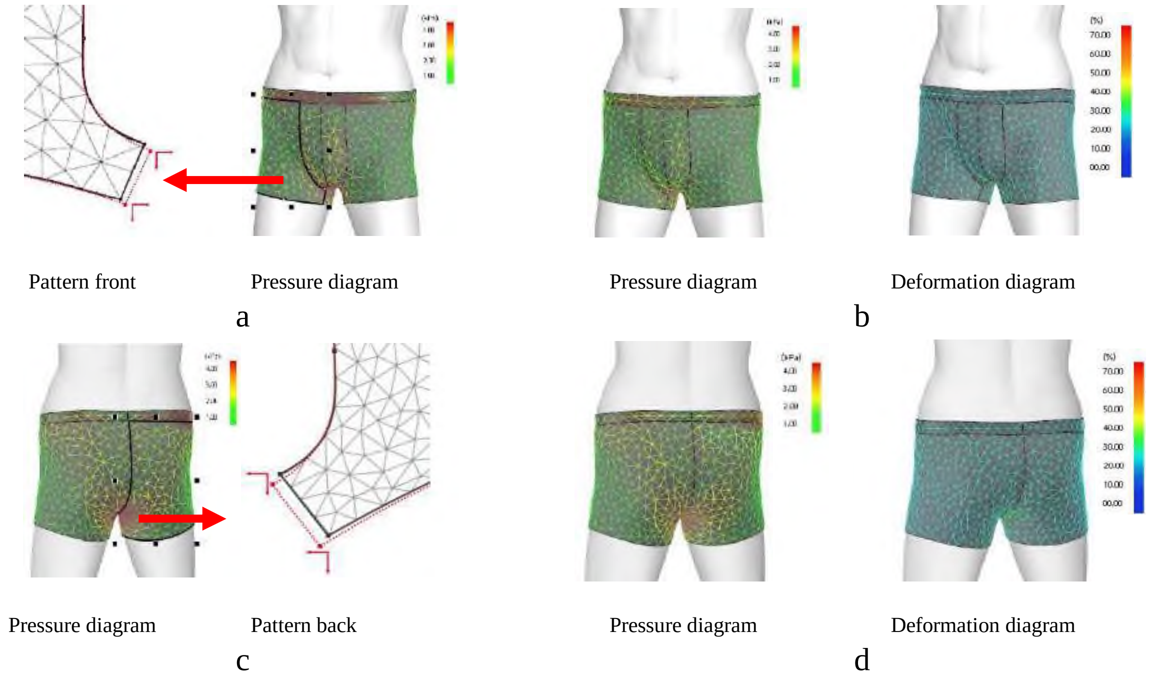


Figure 5.20 – Paired pressure values on body (PB) and virtual (PV): a – the pressure of 14 knitted virtual materials, b – elongated (ease) during -20.0…0.0%

5.3.4. Testing digital twin underwear

We checked the underwear pattern, and tested the virtual pressure sensibility and underwear deformation at various parts [303, 304]. Figure 5.21a shows the virtual underwear (made by T_4) try-on effect in front view. We clearly see that there is an excessive pressure (red color) at the crotch part and front belt. We need to further modify this original pattern. Figure 5.21a left shows the modified front crotch part and belt length of the pattern (increased to the red), and the pressure is lower than before and the deformation at crotch part changed to 32.8…41.2% (Figure 5.21b right). Figure 5.21c, d shows the back view, 2D pattern and 3D simulation.

Figure 5.21e is functional/push-up type Boxers III. Average deformation can reach 32.5%. Combine with the basic underwear, we can see that the independent crotch piece makes the materials stretch at crotch part with a very good performance, outer thigh bottom is very good fit, the design of the structure back line has a good support for the buttock lower.



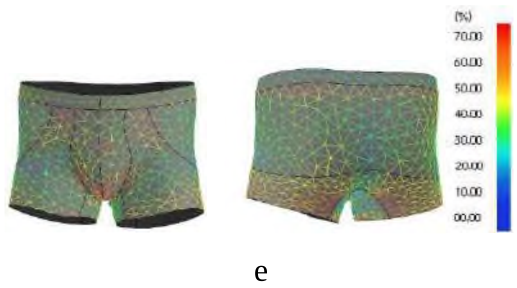


Figure 5.21 – Underwear simulations: a – modify basic type Boxers I front part; b – Boxers I pressure and defamation; c – modify Boxers I back part; d – Boxers I pressure and defamation; e – Boxers III defamation

The range includes five grades: 1 (very low pressure/loose/not fit at some part), 2 (a little low pressure/fit/a few loose), 3 (comfort pressure/close-fitting/tight), 4 (a little high pressure/tight), 5 (high pressure/very tight) to evaluate the final score which was equal to the average grades measured in six parts per underwear.

Table 5.4 – The level of underwear objective evaluation

Levels	**1**	**2**	**3**	**4**	**5**
Scale					
Pressure, kPa	0.3	0.6	0.9	1.2	1.5

For example, Table 5.5 shows the average pressure data. We measured positions of the waistband, bottom girth and hip girth (include front insert and front upper thigh part), because of the pressure difference at the hip girth, we have added measurement points – added into upper, middle and lower as shown in Table 5.5 illustration. The average value of the six measurement sites is 1.08 kPa. That means: the level is above 3.

Table 5.5 – The basic type Boxers I of underwear objective pressure (example of ***M*** size body with ***M*** underwear)

Pressure positions		Buttocks	Front thigh	Sides	Bottom girth	Waistband girth	Front insert
	Upper	1.07	1.56	0.64	0.44	2.10 (front)	0.85 (front)
	Center	1.06	1.02	0.36	0.34	2.70 (side)	0.64 (side)
	Lower	0.63	1.15	0.90	0.28	2.30 (back)	1.02 (back)
	Mean	0.92	1.24	0.76	0.35	2.37	0.84
	S.D., ±	0.25	0.28	0.27	0.08	0.31	0.19

Figure 5.22 shows several examples of pressure distributions of underwear and the rating evaluations. It is calculated by measuring the different positions of underwear, five grades are applied to evaluate the compression underwear from low pressure to high.

As shown in Figure 5.22a and b, we can see that in these two groups (four samples in each group), when the evaluation value is less than "2", the underwear wearing experience will be loose at the upper hip line. For example, as shown in Figure 5.22a, the M^{++} size of the designed product is not suitable for the human body *M*, but in other three groups on the right side, when the *M* body wears the *M* or M^{-}, the evaluation values are during "2-4", the pressure and fit degree is relatively good. This has preliminarily achieved the purpose of tight design of our underwear. But, as shown in Figure 5.22b, the underwear M size dressing on the virtual bodies with the same hip girth and different waist girth has a similar evaluation value about “2-4”.

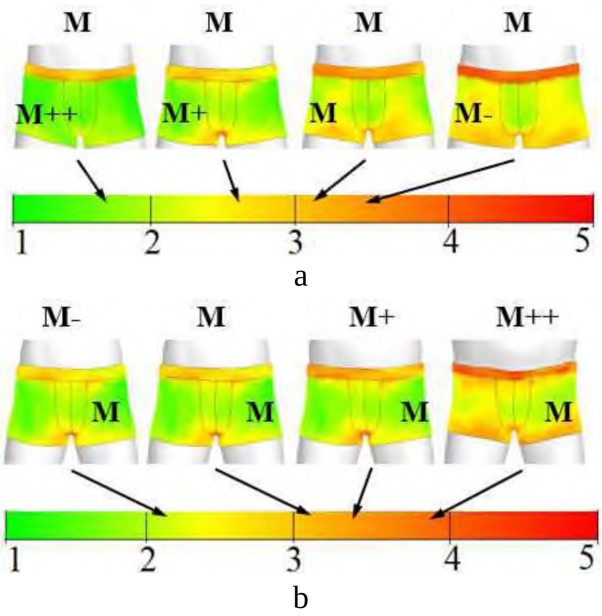


Figure 5.22 – Virtual evaluation of pressure distribution with ease = -19%: a – different sizes underwear on ***M*** body; b – same size ***M*** underwear on different bodies

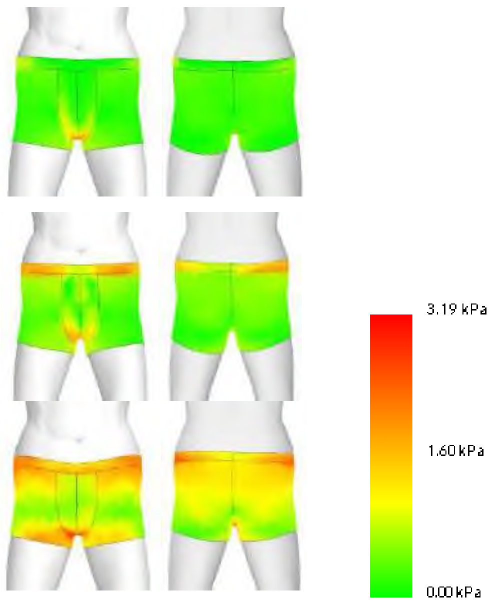


Figure 5.23 – Simulate on body ***M***$^-$***/SM*** and material pressure: Boxers I without additional ease, 0%, -10%, -19%

As shown in Figure 5.23, only high pressure exists in waistband part and lower part of underwear (front insert bottom, crotch area, and the hip area).

The simulated pressure value measurement excludes many factors, such as human soft tissue, bone, knitted material, and sewing thread and so on. Therefore, the virtual underwear style and size we designed can match the bodies well, we have verified that our underwear design methods and knitted material simulation can achieve good virtual finished products. But the practicability of the pressure value needs to be verified in the next step.

5.3.5. Modeling the effect of push-up underwear in a virtual environment

At present, we cannot design the push-up (or lifting the soft tissues by underwear) accurately without real check. So, the virtual detection can be used in parallel to draw conclusions about human try-on evaluation.

This part of research is devoted to the lifting effects that were obtained by two possible ways of functional underwear presentation by forming the both virtual systems:

1) system "initial avatar + functional underwear",

2) system "deformable avatar + functional underwear".

Such approach will help us to evaluate the effectiveness of the functional design of the underwear, and to verify the lifting effect on the soft tissue of the human body from the virtual perspective.

We used three software *MakeHuman*, *3DS MAX* and *CLO*. *MakeHuman* has been used to set virtual avatars with needed measurements by adding the “male genitals” plug in. We created the initial avatar with basic body measurements WG = 77.5 cm, HG = 95 cm, TG = 50 cm. The criteria of virtual model were set according to M size of male body (the same size as the final try-on tester), in order to ensure the comparability.

The algorithm of initial avatar establishment includes the following steps.

1) create a basic 3D male body model and add the “genitals model” by *MakeHuman*.
2) adjust some basic body sizes (WG, HG, TG…) in line with the real human body, and make genitals part in natural falling state, adjust its size to be approximately the size of Asians, near the average volume with Asian male, this size can only be set by observing the visual size (Figure 5.24 a).
3) Export the file of initial avatar in “obj” format.

The algorithm of deformable avatar building includes the steps by *3DS MAX*.

1) Import model of initial avatar, lifting the “soft tissue” – adding push-up effects according to a fixed value.

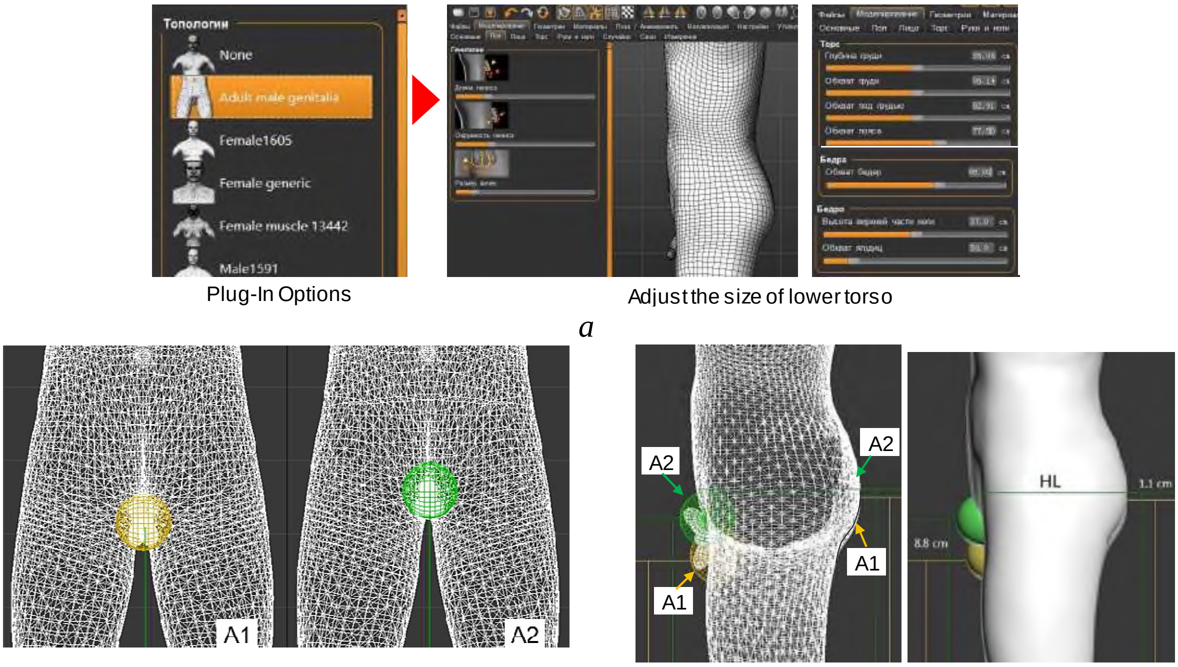
2) Change the height and state of the genitals part to upward state.

3) Change the height of the buttocks level.

Figure 5.24 b and c show the movement and rotation of "virtual component" positions, the algorithm of deformable avatar preparation in *3DS MAX*. To get the deformable avatar, we adjusted the largest values of the push-up effects by *MakeHuman* in according with the previous research (see Chapter 3) in front 8.8 cm and in buttocks 1.1 cm (Figure 5.24 d).

Due to the limitations of *MakeHuman*, it was impossible to simulate lifting effect on male genitals. Therefore, we used *3DS MAX* software to adjust the male genitals and change its position as the result of simulation of being lifted effect. Because the "genitals part" considered in software as solid, non-deformable and hard, it was difficult to simulate an effect under the virtual underwear after try-on. We are treating the virtual male genitals as a sphere with the volume just completely cover the entire "genitals" part. For this limitation, we have chosen the measurement method at the beginning of this study and used *3DS MAX*. We build two virtual bodies in the same space with the yellow sphere without push-up effect and the green sphere after pushing up, the two spheres are in same size, and we can see the "genitals" position changes from the perspective (Figure 5.24 b, c, d).

The deformable avatar with predictable push-up effect was designed, which should be got by means of functional underwear. As Figure 5.24 c shown, we can see the position of the two spheres representing the displacement of the genitals, the green sphere after lifting looks more prominent due to the pubic bones and hold the whole genitals part make them tightly together. We can also see the buttocks upper and looks firmer. Therefore, the lifting effect not only has a good support or wearing comfort for the male, but also produces a good visual effect – highlighting the male gender beauty.



a

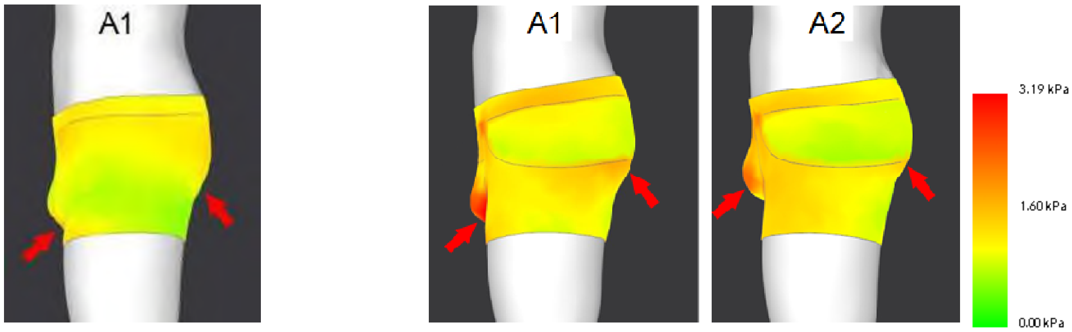
b *c* *d*

Figure 5.24 – Screenshots of *MakeHuman* after designing of initial avatar (*a*); front views of avatars with genitals parts as spheres named initial A1 (yellow) and deformable A2 (green) in *3DS MAX (b)*; profile views of nude avatars before and after lifting (*c*); the overlapped profiles and comparison of the push-up value (*d*)

Before virtual try-on of the same functional underwear, we created two avatars as Figure 5.24 d shown: initial avatar *A1* with the genital natural fall and buttock shape; deformable avatar *A2* with the genitals lifted in 8.8 cm and the buttocks lifted in 1.1 cm.

Subsequently, we conducted virtual try-on experiments with underwear of Boxers I and III – basic Boxers I without push-up functions and functional underwear Boxers III with the same eases. Wed selected knitted material *T2* with good elasticity, large thickness and 1st level *CP* (highest) for testing to see the strongest push-up effect. A simulation experiment of the virtual knitted material performance with *CLO* was completed.

Figure 5.25 shows the virtual try-on tests, the virtual underwear with basic style and functional style (with push-up effect) dressed on two body models *A1* and *A2*.



Initial avatar *A1* + basic type underwear
a

Initial avatar *A1* + functional underwear
b

Deformable avatar *A2* + functional underwear
c

Figure 5.25 – Virtual systems “avatar-underwear” in CLO: a – initial avatar *A1* + basic underwear Boxers I without push-up effects, b – Initial avatar *A1* + underwear Boxers III with push-up effects, c – deformable avatar *A2* + underwear Boxers III with push-up effects

Figure 5.25 a shows the avatar *A1* wearing the basic underwear Boxers I without design push-up effects. After opening the “pressure view” in *CLO*, we can see that try-on performance is normal, there is no high pressure, the overall value distribution is lower than the middle of the pressure scale, only the front waistband/anterior superior iliac spine, the upper part of buttocks and the front genitals bottom have higher pressure near 0.75...1.26 kPa.

Figure 5.25 b shows the initial avatar *A1* wearing the functional underwear Boxers III designed with push-up effects in front and back. As we can see, underwear Boxers III produced the pushing up effects under the genital and the buttocks below *HL*. Because the virtual avatar is fixed and hard, all of these parts are under large pressure 1.78...3.15 kPa. Therefore, the presentation is not reflecting the predicted effect of underwear.

Figure 5.25 c shows the results when the avatar soft parts were lifted, and the sizes were adapted after applying the maximum push-up effects. We can clearly see that the red large pressure area at the bottom of the genitals becomes smaller. Due to preparation of avatar, the genitals and buttocks soft tissues have no gravity effect, but there is still high pressure on two parts of front insert and buttocks. That is to say, after the male genitals has been lifted by 8.8 cm, these additional material pressures still give this soft tissue a good support. As for the comparative observation of the buttocks part, the pressure value also changes smaller. Similarly, there is a pressure value near the structural line to continue to support.

Moreover, *MakeHuman* and *3DS MAX* can accurately build and adjust male body model and *CLO* software can simulate real knitted material properties very well. Subsequently, we through about the production of virtual underwear, try-on test, and the simulation of functional effects. It can be also seen from the simulation that the apparent wear effect changes and measure the virtual pressure value. However, the wearing comfort of underwear cannot be tested by simulation accurately, and only can be judged based on the pressure and the degree of deformation of the fabric. Moreover, due to the solid-state characteristics of the body model, the test results (push-up value) of the functional effect are also unknown from the simulation. The comfort level of the human body can be improved when the proper pressure is provided at the soft tissue.

5.4. Experimental verification

5.4.1. The establishment of differences between boxers of different types

We have made two pieces of Boxers I prototype made by T_4 – 2nd level of *CP* index (high pressure), with the median thickness and common composes, and the maximum acceptable elongation E = 19%. Used the method of “mass production drawing mode” following Table 5.2, and then wearing on the bodies S^+/SS, M^-/SM. We named them as “B1” and “B2” for next step experiment. And we can see them in Figure 5.26.

As for this comparison, firstly, we can see the photos of underwear Boxers I with the additional ease 0% (Figure 5.26 a, b in the left), and -19% in the right. Two samples with 0% have looser and less supporting for front and back. But, another sample with -17% design ease have more tightly felt, it can be well accepted, and have some folds in front insert sides and buttocks lower.

a b

c d

Figure 5.26 – Comparison of finished Boxers I and try-on, with the ease 0% and -19%: a, b – “B1” size of **S^{+}/SS**; c, d – “B2” **M^{-}/SM**

Through two males try-on experiment, in total, they prefer the Boxers I with ease of -19% and advise that the ease value can be designed during -19…0%, with not very tight subjective feelings. At front insert, this part has good supporting but not spacious (insufficient activity space) because of the basic front insert structure.

5.4.2. Evaluation of the push-up effect

After, we used the different of four kinds knitted materials in Figure 5.27 (are T_1 – 2nd level of *CP* index; T_2 – 1st level of *CP* index; T_6 – 3rd level of *CP* index; T_{11} – 2nd level in warp, 3rd level in weft of *CP* index). Four materials in different styles, with good elasticity, common materials used in the market, Boxers III with the same *E* (ease were taken the mean is -19%), and named them as “U1, U2, U3 and U4”. We use the same ease “-19%” to make a test. The dressing figures in static posture as shown in Figure 5.27.

Figure 5.27 – Underwear made of 4 kinds materials: a – “U1” with T_1; b – “U2” with T_2; c – “U3” with T_6; d – “U4” with T_{11}

As for this comparison, firstly, we can see the photos of underwear Boxers III with the additional ease -19%. But depending on the thickness and density of the 4 knitted materials, samples “U1” and “U3” are much easier to get folds below the buttock. The knitted material of “U2” has the smallest shrinkage during stretching, about 0.07% shrinkage for per 1% stretched; the shrinkage of other 3 materials during 0.13...0.67% for per 1% stretched. So, we can find the “U2” has a concave down at the bottom line in the profile. “U4” has the larger shrinkage value, so, this underwear looks shorter.

Subsequently, in order to compare the push-up effect of the underwear, the 3D scan profiles of the lower torso as shown in Figure 5.28. The first one is the tester's own underwear, his own Boxers is very tight, others 3 (B2, U2, U4) are our designed Boxers. We can see that the value “a” are significantly different. The U4 & U2 have the higher front and buttocks levels. Due to the difference in fabric properties and structural design, the push-up effect is also different.

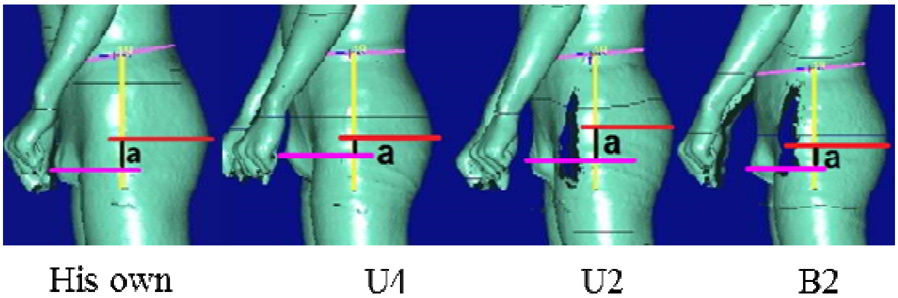


Figure 5.28 – Torso soft tissue correction schemes for the male figure front and back for a push-up effect

5.4.3. Sensory evaluation

Subjective assessment was based on a five-point scale. The scale included the following ratings: 5 - very comfortable, 4 - comfortable, 3 - satisfactory (general), 2 - uncomfortable, 1 - very uncomfortable. The experts were instructed on the rules for grading. The number of experts – 7 people aged 25…27 years.

Comfort convenience boxers checked when performing daily movements: squatting at different depths, step, lifting legs and a short walk for 3-5 minutes with alternating long and short steps. Experts were asked to evaluate the sensations arising: in the following areas of the body: overall, waist, in the genital area (front insert), in the crotch area, hips, buttocks; from contact with underwear: material, structure of underwear; from push-up effect: front and back; in various postures: sitting, walking, lifting a leg, squatting. The results of subjective feeling as shown in Figure 5.30.

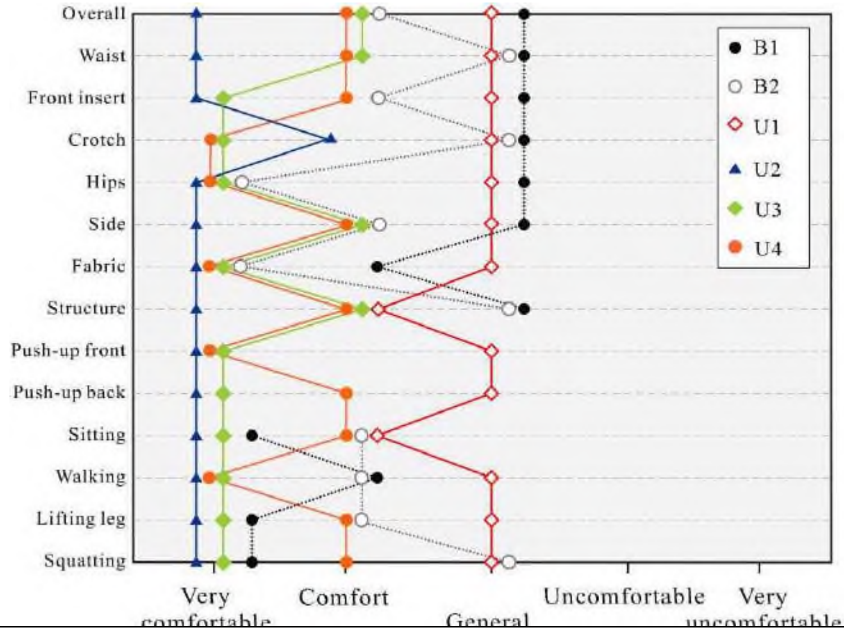
In totally, we can see that except “B1” and “U1”, the “U2” has very good wearing feeling and score in dynamic and static conditions. Functional underwear can provide good push-up effects. None of the samples produced uncomfortable feeling. When the knitted material has poor elasticity, the feeling of the “lifting leg” and “squatting” postures and the pressure performance are worse than static feelings.

Through our try-on experiments, based on the comfortable feeling to choose the Boxers in the order from like to dislike “U2”-“U3”-“U4”-“B2”-“B1”-“U1”.

- The “B1” and “U1” without tight feeling, because of the soft and thin knitted material properties. Moreover, materials T_1 and T_4 have low *WT* (tensile energy), but lowest *RT* (tensile resilience) and low *RC* (compressive resilience) by KES, that means they have the common stretch elasticity, but poor resilience, thick but hard feeling.
- “U4” made of tight, hard and thick knitted material, so this Boxers III has a little tight when the tester wearing it. “B2” is basic type and basic insert piece, it cannot make the male front soft tissue feel relaxed.
- “U2” and “U3” have good performances in try-on test in static and dynamic conditions; “U3” can be designed more tightly. Moreover, materials T_2 and T_6 have the good indexes of smallest *WT*, largest *RT* and largest *RC* by KES, that means they have good stretch elasticity, resilience (easy to stretch, and very good for recovery), thick fluffy and not stiff feeling. Material T_4 has the best parameters of *EMT.*

a b c d

Figure 5.29 – Actions for dynamic test: a – setting; b – stride (walking); c – squatting; d – lifting leg

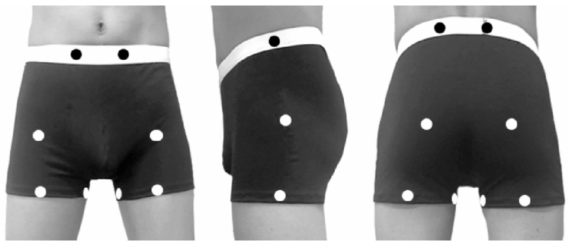


Holistic rating of subject evaluation						
Underwear	B1	B2	U1	U2	U3	U4
Scores	3.7	3.8	3.1	4.9	4.7	4.4

Figure 5.30 – Subject evaluation diagram

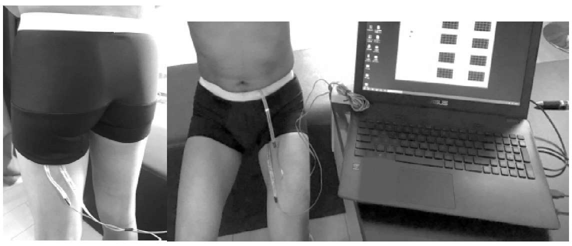
5.4.4. Pressure measurement and verification of virtual pressure

Pressure sensors have also measured for the objective test. The methods and test points as showed in Figure 5.31. The measured values as shown in the Figure 5.32.



a

b



c

Figure 5.31 – Pressure measured on Boxers and I and III: a – positions (on the structural line); b – standing and dynamic test status

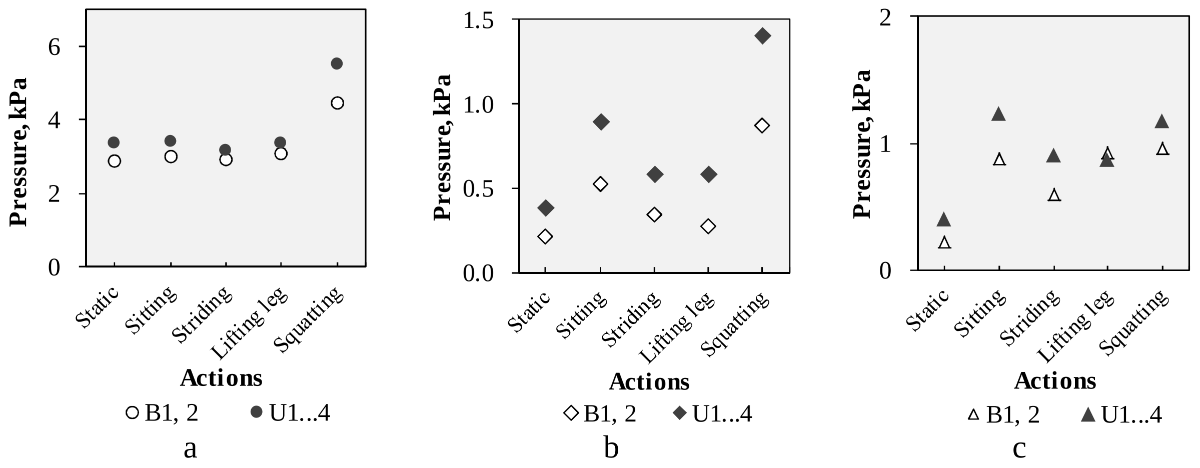


Figure 5.32 – Average pressure values measured from Boxers I and III: a – waist position; b – hips and front thighs; c – thigh bottoms

Compare with the simulated pressure results of measurements and body in Figure 5.32. Boxers I is simulated with the ease -19…0%, the samples for try on tests are made of ease -19% (different to measure pressure in ease equal to the 0). The average values of some body parts in the static (standing) and dynamic conditions of virtual model simulation and real body try-on as shown in Table 5.6.

Table 5.6 – Virtual and actual pressure comparison, kPa

	Measurement	Waistband	Hip	Bottoms
Boxers I	Virtual standing	1.36...2.57	0.73…1.38	0.85…1.77
	Real standing	2.89…4.44	0.22…0.87	0.23…0.96
	Real squatting	5.14	1.41	1.63
Boxers III	Virtual standing	1.76…2.84	1.84…2.13	1.15...2.28
	Real standing	3.37…4.79	0.38…1.14	0.40…1.23
	Real squatting	5.98	2.19	1.52

According to the comparison in Table 5.6, the pressure values of the virtual and real are different, but the difference is not large, the virtual design of the underwear is closer to the real pressure range. It should be noted that the push-up style underwear produce higher pressure values at the three positions. The virtual pressure is smaller than the real measured at the waistband, but greater than the real pressure at the hips and bottom/thigt, which is due to the characteristics of the soft tissue of the human body, so that the real measured pressure value is small.

5.4.5. Check the theoretical and actual pressure values

As for the equations we have mentioned before in the chapter 4, we also checked this predict evaluation of the pressure values provided by knitted materials of the Boxers I and III, all Boxers are designed with ease -19%, the average of predicting pressure values are higher than the measurements, but only 0.22 kPa (in Table 5.7).

As can be seen from the test results, the functional design, characteristics of knitted material affect the scores (good feeling for try-on). T_2, T_6 have good elasticity (smallest *WT*, largest *RT* and largest *RC* in KES results). And knitted material thickness (T_2 thick, T_6 thin) does not affect the pressure value.

Table 5.7 – Mean of pressure values by measure and predict, kPa

Samples' material	Measuring P	Predicting $\hat{P}$		Avg. difference
		Eq. (4.10)	Eq. (4.8)	
T_1	1.18	1.88	1.86	+0.69
T_2	1.29	1.93	1.92	+0.64
T_4	1.11	1.81	1.82	+0.71
T_6	1.19	1.90	1.88	+0.70
T_{11}	1.28	1.94	1.92	+0.65
Mean	*1.21*	*1.89*	*1.88*	*+0.67*

After comparing the predicted pressure value with the real one, we found that the values calculated by the two preferred equations are greater than the real pressure value, which is increased 0.67 kPa. Therefore, we can modify these two equations to make the prediction result accurate.

In the final form of the equation will take the form:

Original equations		Equations after correction	
$P_{\max} = e^{\left(0{,}750 - \frac{7{,}404}{F(E_{\max})_{\text{weft}}}\right)}$	(4.10)	$P_{\max} = e^{\left(0{,}750 - \frac{7{,}404}{F(E_{\max})_{\text{weft}}}\right)} - 0.68$	(5.3)
$P_{\max} = e^{\left(0{,}765 - \frac{3{,}886}{F(11)_{\text{weft}}}\right)}$	(4.8)	$P_{\max} = e^{\left(0{,}765 - \frac{3{,}886}{F(11)_{\text{weft}}}\right)} - 0.67$	(5.4)

5.4.6. Comparison of developed designs with existing ones

We compared the patterns of boxers, developed by the existing and new design methods, without side seam for the same shape.

It is seen that in the known methods there is a huge variety in the design of the contour and internal lines, not supported by the requirements of the form or features of the bodies.

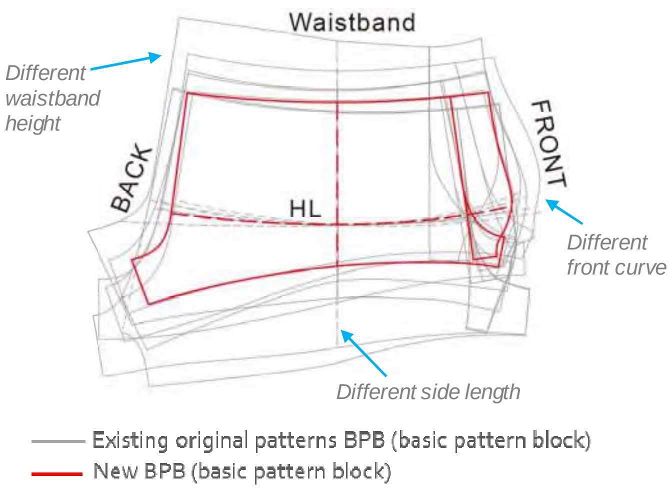


Figure 5.33 – Comparison of developed and existing design methods

1. The middle lines of the back of the prototypes have different length, slope and width of the step. Obviously, the short line will lead to discomfort in the crotch area, and too long will contribute to the rapid deformation of boxers

during movements. But nevertheless, it is possible to speak about the similarity of the middle lines in the well-known drawings and the line from the developed BPB, their proximity to the analogues from the designs of the trousers.

2. The middle line of the front in the BPB and the known methods are completely different. In the prototypes, their design is not structured.

3. The configuration of the insert in the developed BPB has no analogues among known prototypes.

Thus, the visual analysis of the developed BPB and known prototypes showed their absolute dissimilarity.

5.4.7. Production inspection

The test certificate is placed in Appendix VI.

Summary of chapter 5

1. A method for designing and grading men's underwear has been developed, based on new dimensional features and the developed scheme for the classification of the lower parts of male bodies.

2. Experimental verification of a new design method was carried out by constructing underwear (boxers) for various purposes – without deforming soft tissues (boxers of type I) and with deformation of soft tissues, with their compression and upward movement (boxers of type III). The method of sensory analysis confirmed the correctness of the correctness of the design decisions.

3. The influence of indexes of the physic mechanical properties of knitted materials on the sensations of comfort has been studied. It is established that the best feelings arise when using materials with low WT values, and high RT and RC values. This ensures good elasticity under tension and elasticity.

4. The possibility of computer simulation is shown and proved to change the morphology of the lower parts of the bodies and to carry out the fitting of underwear in computer programs MakeHuman, 3DS MAX and 3D CLO. Classification of male bodies and sizes of underwear were tested using 3D modeling technology. From the standpoint of ensuring the necessary pressure on soft tissues and deformation of the material and the possibility of adjusting the original 2D drawings.

5. It is shown that the convergence of experimental and theoretical results can be maximally achieved by introducing a correction factor.

6. The developed method of constructing boxers was transferred to the enterprise ZOZH (Ivanovo) for the release of an experimental batch.

RESULTS OBTAINED

1. The main directions in changing the anthropomorphic and aesthetic features of the lower part of the torso of male bodies, achieved through artistic and constructive solutions of men's underwear, including the positions of contour lines relative to the anthropometric levels of the body, overall dimensions, design of lines of internal division. The ranges of the position of the contour lines of underwear on the surface of male bodies are determined.

2. On the basis of an expert survey of a large group of consumers from different countries, their preferences regarding the existing range of men's underwear were established and the main problems arising from its purchase and operation were identified, which made it possible to actualize the content of scientific research.

3. A new nomenclature of dimensional features has been developed, necessary and sufficient for describing the anthropomorphic features of male bodies with initial shape and after it has been modified under the influence of

the mechanical effect of compression underwear, and also suitable for calculating design parameters and building drawings. For the first time, typical cross sections of between the right and left parts of the male torso in the middle sagittal-plane were obtained.

4. Experimentally determined boundaries of sections of the male body, for which it is possible to design the maximum level of short-term compression pressure of soft tissues by clothes.

5. A new index of compression ability for knitted fabrics has been developed, which characterizes their ability to create maximum pressure on the soft tissues of the body, depending on the degree of narrowing of the underwear relative to the body girth.

6. Equations are obtain for predicting the compression pressure under stretched textile shells and checking the sufficiency of the chosen structural additions to achieve the required pressure.

7. The boundaries of soft tissue correction for male bodies front and back were experimentally established and an algorithm for computer simulation of targeted shape changes on digital twins of bodies and underwear was developed.

8. A new methodology for designing men's underwear has been developed, based on new dimensional features and gradation scheme, implemented in traditional and computer-aided design.

RECCOMENDATIONS, PERSPECTIVE OF FUTURE DEVELOPMENT

9. The results of the work are recommended to be used in the educational process of universities that train bachelors and masters in the direction of “Designing products of light industry” and CAD development.

10. In the future, the design concept of tight-fitting men's underwear can be improved in terms of adapting to the medical, corrective and sports areas by structuring underwear and targeted pressure distribution.

11. It is promising to use body scanning technologies to obtain more accurate anthropometric information, describe morphological differences, and develop a labeling scheme for underwear.

12. The results of the work can be used in the field of practical artistic and industrial design, education and advanced training for a qualitative change in existing concepts and the development of new, digitalization-oriented economies.

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APPENDIX I

The results of analytical reviews, expert estimates and statistical processing chapter 2

Table I.1 – KMO and Bartlett's Test and Total Variance Explained

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.				0.89		
Bartlett's Test of Sphericity	*Approx. Chi-Square*			900.59		
	df			66		
	Sig.			0.00		
No.	*Initial Eigenvalues*			*Extraction Sums of Squared Loadings*		
	Total	*% of Variance*	*Cumulative %*	*Total*	*% of Variance*	*Cumulative %*
1	5.08	42.29	42.29	5.08	42.29	42.29
2	1.32	10.99	53.28	1.32	10.99	53.28
3	1.02	8.47	61.75	1.02	8.47	61.75
4	0.76	6.31	68.05	0.76	6.31	68.05
5	0.67	5.61	73.67	0.67	5.61	73.67
6	0.59	4.87	78.54	0.59	4.87	78.54
7	0.57	4.71	83.24	0.57	4.71	83.24
8	0.51	4.27	87.51	Extraction Method: Principal Component Analysis.		
9	0.46	3.81	91.32			
10	0.42	3.46	94.78			
11	0.36	3.03	97.81			
12	0.26	2.19	100.00			

Table I.2 - Rotated Component Matrix[a]

	Component						
	1(X_5, X_1, X_4)	2 (X_{12} и X_2)	3 (X_8 и X_9)	4 (X_{11} и X_3)	5 (X_6)	6 (X_7)	7 (X_{10})
X1	0.84	0.14	0.13	0.26	0.09	0.05	0.07
X2	0.31	0.79	0.08	0.01	0.19	0.16	0.07
X3	0.43	0.08	0.28	0.58	0.26	-0.07	0.17
X4	0.59	0.13	0.13	0.18	0.36	0.31	0.20
X5	0.87	0.14	0.09	0.12	0.11	0.05	0.17
X6	0.22	0.08	0.18	0.19	0.90	0.02	0.09
X7	0.11	0.22	0.23	0.09	0.02	0.91	0.03
X8	0.09	0.07	0.91	0.01	0.14	0.13	0.06
X9	0.22	0.24	0.67	0.32	0.09	0.20	0.15
X10	0.25	0.12	0.14	0.20	0.11	0.04	0.92
X11	0.24	0.22	0.07	0.83	0.14	0.16	0.16
X12	0.03	0.84	0.14	0.24	-0.05	0.11	0.07

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 6 iterations.

Table I.3 – The distribution of underwear styles preferences, %

Types	Age groups				Total
	>25	25...35	35...55	>55	
1	2	3	4	5	6
Briefs	18.5	20.7	18.4	**30.4**	16.7
Trunks	**21.4**	**26.4**	23.0	16.1	**28.1**
Boxers	19.4	20.2	19.5	17.9	17.5
Boxers (loose-fitting)	21.0	24.4	**24.1**	23.2	18.7
Jockstraps	14.5	7.3	9.2	14.3	5.2
Bikinis	11.7	10.3	13.8	8.9	3.3
Thongs	14.9	17.1	14.9	5.4	10.4
Very close-fitting	12.6	19.8	5.3	16.1	26.7
Close-fitting	**33.3**	**36.7**	26.3	11.3	**38.5**
Regular	32.2	25.1	**34.6**	24.2	24.6
Loose-fitting	21.8	18.4	33.8	**48.4**	11.1

Table I.4 – The comparison of preferences and ownerships proportion, %

Underwear Types	Chinese		French		Russian		Indian	
	Prefer	Own	Prefer	Own	Prefer	Own	Prefer	Own
1	2	3	4	5	6	7	8	9
Briefs	15.8	20.1	8.1	24.7	5.7	20.3	16.7	18.2
Trunks	25.3	22.2	5.4	16.0	71.4	37.5	50.0	27.3
Boxers tightly	12.4	17.6	78.4	29.2	11.4	12.5	16.7	18.2
Boxers loosely	17.9	13.5	6.8	12.8	8.6	18.8	0.0	9.1
Bikinis	3.2	4.4	0.0	2.3	0.0	0.0	0.0	0.0
Jockstraps	5.0	5.5	1.4	0.0	0.0	0.0	0.0	18.2
Thongs	10.3	8.0	0.0	0.0	0.0	0.0	0.0	0.0
Others	7.0	-	0.0	-	0.0	-	0.0	-
Do not wear	3.0	-	0.0	-	2.9	-	16.7	-
Swimwear	-	8.7	-	15.1	-	10.9	-	9.1

Table I.5 – Cross-tabulation of Chinese respondents' preferences (Boxer-briefs/Boxer-shorts), %

Preferences		Very dislike	Dislike	General	Like	Very like
Age groups	Teenager	20.0 20.0	0.0 40.0	0.0 20.0	60.0 20.0	20.0 0.0
	20...25	1.6 1.6	14.5 6.5	25.8 32.3	50.0 43.5	8.1 16.1
	26...35	0.0 6.9	12.1 10.3	27.6 29.3	50.0 43.1	10.3 10.3
	36...55	0.0 1.3	5.3 6.7	29.3 41.3	53.3 37.3	12.0 13.3
	>55	0.0 0.0	0.0 25.0	0.0 0.0	75.0 50.0	25.0 25.0
Total		1.0 3.4	1.0 3.4	9.8 8.8	26.5 33.8	52.0 40.7

Table I.6 - The proportion of structural feature preferences, %

Features	Chinese	French	Russians	Bangladeshi
1	2	3	4	5
Very close-fitting	31.3	8.1	0.0	0.0
Close-fitting	34.5	52.7	56.7	60.0
Regular	21.5	35.1	43.3	20.0
Loosely	12.8	4.1	0.0	20.0
Seamless	27.9	12.2	26.7	20.0
Few seams	38.3	20.3	36.7	80.0
Many seams	16.2	0.0	3.3	0.0
Unclear	17.7	67.6	33.3	0.0

Table I.7 – Summary of research results

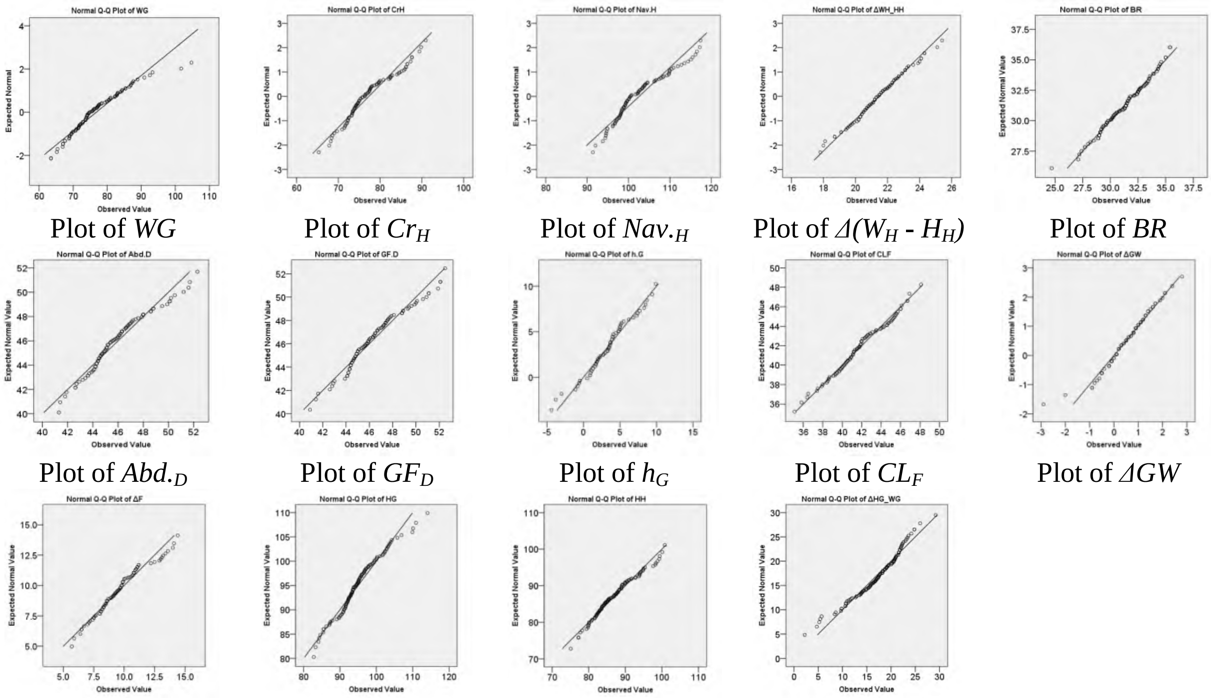
No.	Pressure range (value) at different part, kPa		Comfortable mean, kPa	Researcher
1	2	3	4	5
1	Body	1.19...3.19	2.68	M.J. Denton
2	Body (soft sites)	1.99...4.39	-	H.P. Giele
3	Waist	3.18...6.37	-	O. Shizue
4	Waist, thigh	4.00...5.33	2.46 (Waist)	H. Makabe
5	Waist, thigh, hip	0.80...1.30	-	N. Ito
6	body	1.99...3.33	-	D. Tanaka
7	Hip, thigh, calf	2.40...3.09	1.08	T. Tamura
8	Torsos, biceps	-	2.26	T. Kobayashi
9	Bust, waist, hip	4.95...4.98	-	M. Sato
10	Calf, mid-calf	2.10...3.70	<4.50	T. Toshiyuki
11	Waistband, thigh, knee	1.73...5.93 1.65...3.93	2.22...3.00	L. Mingxia
12	body	0.32...1.46	-	J. Ziming
13	lower limbs	0.04...0.17	-	X. Meiling
14	lower limbs	0.40...2.50	-	Y. Pei
15	Abdomen, hip	0.72...1.27	0.72...1.75	L. Yaping
16	Abdomen	0.88...1.07	-	L. lulu
17	abdomen, hip, thigh, calf	0.96...1.84	-	L. Yao
18	Mid-waist, hip, thigh	2.30...3.89	3.89	G. Lei
19	Waist, hip, crotch, leg	2.00...3.70	-	J. Erfan
20	body	0.29 ... 1.49	-	J. Zhennan
21	arms	-	2.29...3.41	Z. Lin
22	Hip, thigh	0.4...1.29	-	L. Huashan
23	Bust, waist, hip, shoulder	0,28…1,21	-	G. Mengna
24	Under bust, waist, hip, thigh, knee	1,10…3,55	-	I. Tislenko

APPENDIX II

The results of statistical and graphical analysis of male figures

Table II.1 Correlation coefficient between new and traditional measurements

Additional measure-ments	Correlation coefficient r / sig.										Number of r for strong relation-ship
	Traditional body measurements			Primary measurements							
	W_G	H_G	CL	WB_D	HB_D	GF_D	$Abd._D$	$\Delta(W_H - H_H)$	H_{SL}	T_{SL}	
1	2	3	4	5	6	7	8	9	10	11	12
ΔGW	0.05	0.11	0.09	0.08	0.15	0.30	-0.06	0.13	-0.03	0.24	0
	0.67	0.28	0.39	0.46	0.14	0.00	0.55	0.23	0.51	0.88	0
ΔWH	0.07	0.08	-0.14	**0.50**	**-0.42**	-0.24	-0.22	-0.21	-0.12	-0.26	2
	0.51	0.48	0.19	0.00	0.00	0.02	0.03	0.05	0.49	0.11	2
$\Delta(H_G - W_G)$	-0.25	-0.01	0.03	0.26	0.26	0.16	0.13	0.24	0.16	-0.02	0
	0.01	0.89	0.81	0.01	0.01	0.13	0.22	0.01	0.03	0.38	0
ΔF	0.09	0.17	**0.57**	-0.13	0.13	**0.42**	**0.36**	-0.03	-0.22	**-0.43**	**4**
	0.41	0.09	0.00	0.20	0.74	0.00	0.00	0.78	0.22	0.01	3
ΔB	0.23	0.24	**0.52**	0.13	**0.37**	**0.40**	**0.36**	-0.11	0.19	-0.20	**4**
	0.09	0.17	0.00	0.01	0.00	0.00	0.00	0.28	0.28	0.26	4
BR	0.32	**0.49**	0.22	0.14	0.29	0.28	0.25	**0.34**	0.29	0.14	2
	0.00	0.00	0.00	0.23	0.22	0.00	0.00	0.00	0.34	0.15	6
$Nav._H$	-0.05	0.16	**0.41**	0.22	**0.36**	0.14	0.13	**0.40**	0.19	0.32	3
	0.59	0.09	0.00	0.21	0.00	0.00	0.00	0.00	0.29	0.07	5
GF_H	-0.08	0.12	0.22	0.14	0.29	0.28	0.25	**0.34**	-0.07	0.16	1
	0.52	0.37	0.08	0.27	0.02	0.03	0.05	0.01	0.00	0.10	1
Cr_H	-0.05	0.16	0.20	-0.16	-0.04	0.19	0.15	-0.13	-0.03	0.51	0
	0.59	0.09	0.56	0.04	0.00	0.18	0.23	0.00	0.12	0.04	2
h_G	0.03	0.16	**0.57**	-0.14	-0.04	**0.46**	**0.47**	-0.03	**-0.46**	0.25	4
	0.84	0.23	0.05	0.17	.010	0.01	0.03	0.17	0.07	0.69	0
h_H	0.29	0.21	**0.52**	-0.27	**-0.44**	**0.39**	**0.42**	-0.11	-0.20	-0.21	4
	0.00	0.02	0.04	0.14	0.73	0.07	0.15	0.17	0.07	0.86	1
CL_F	0.06	0.20	**0.94**	-0.08	0.12	**0.65**	**0.64**	0.31	-0.05	0.05	3
	0.57	0.05	0.00	0.44	0.25	0.00	0.00	0.00	0.94	0.78	4
CL_B	0.17	0.26	**0.94**	-0.17	-0.15	**0.63**	**0.63**	0.26	0.09	0.09	3
	0.10	0.01	0.00	0.10	0.16	0.00	0.00	0.01	0.11	0.64	3
NW_G (-8)	**0.50**	**0.46**	0.13	-0.16	-0.27	0.25	0.23	-0.06	-0.21	0.12	2
	0.00	0.00	0.24	0.29	0.02	0.01	0.02	0.85	0.90	0.39	2
NT_G (CrL, 0°)	0.02	0.06	0.04	-0.09	-0.10	0.02	-0.05	0.07	0.03	0.10	0
	0.86	0.52	0.71	0.38	0.33	0.86	0.66	0.46	0.26	0.89	0



Plot of *WG* | Plot of Cr_H | Plot of $Nav._H$ | Plot of $\Delta(W_H - H_H)$ | Plot of *BR*

Plot of $Abd._D$ | Plot of GF_D | Plot of h_G | Plot of CL_F | Plot of ΔGW

Plot of ΔF | Plot of *HG* | Plot of *HH* | Plot of $\Delta(H_G - W_G)$

Figure II.1 Normal distribution plots of body measurements

Table II.2 - Statistics of waist part by SPSS, cm

		Primary data	Additional data		
		W_G	Cr_H	$Nav._H$	$\Delta(W_H - H_H)$
Descriptives	Min.	63.5	65.3	91.4	17.8
	Max.	93.3	90.9	117.4	26
	Mean	76.24	77.5	102.57	21.51
	S.D., ±	6.81	5.26	6.27	1.66
Percentiles	Q_1	72.7	73.5	98.2	20.3
	Q_2	76.1	76.8	100.5	21.5
	Q_3	82.8	80.8	106.7	22.7
Statistic for controlling the normal distribution		0.13	0.42	0.12	0.99

Table II.3 – Statistics of the bodie front by SPSS, cm

		Primary data			Additional data			
		BR	$Abd._D$	GF_D	h_G	CL_F	ΔGW	ΔF
Descriptives	Min.	24.7	41.3	40.9	-4.4	35.1	-2.9	5.7
	Max.	35.4	52.3	52.7	8.7	48.1	2.8	13.6
	Mean	31.51	46.01	46.82	3.13	40.51	0.49	9.41
	S.D., ±	1.94	2.41	4.36	2.86	2.57	0.68	1.52
Percentiles	Q_1	29.7	44.4	44.7	1.65	40.2	0	8.3
	Q_2	31.4	45.4	46	3.5	41.6	0.5	9.5
	Q_3	32.7	47.1	47.6	4.95	43.5	1.1	10.7
Statistic for controlling the normal distribution		0.12	0.08	0.45	0.09	0.41	0.18	0.54

Table II.4 – Statistics of the bodies hip by SPSS, cm

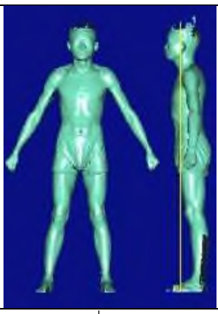
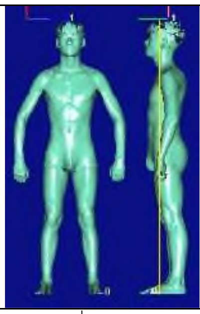
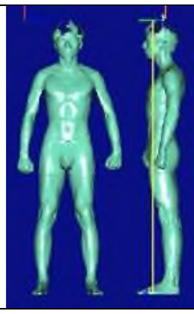
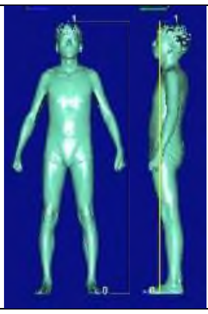
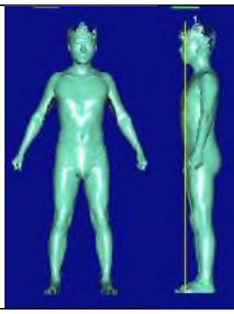
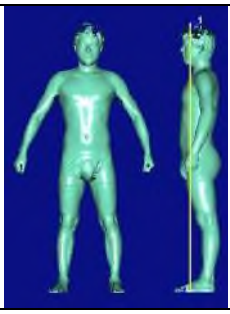
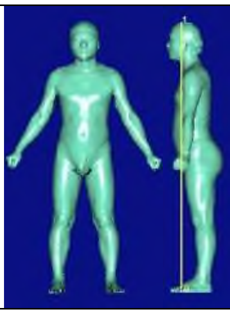
Primary data					
		H_G	WB_D	HB_D	H_H
Descriptives	Min.	82.8	22.4	20	75.1
	Max.	114.1	31	25.8	99.4
	Mean	94.24	25.08	21.24	86.56
	S.D., ±	5.5	1.57	1.53	4.86
Percentiles	Q_1	91.8	24.05	20.1	82.95
	Q_2	94.5	25	20.5	86.9
	Q_3	97.9	26	21.75	89.95
Statistic for controlling the normal distribution		0.11	0.05	0.05	0.24

Additional data						
		CL_B	h_H	ΔWH	ΔB	$\Delta(H_G - W_G)$
Descriptives	Min.	34.1	4	1.1	3.6	8.4
	Max.	45.8	13.2	8.8	14.5	28.5
	Mean	38.69	9.59	3.88	7.59	18
	S.D., ±	2.2	1.73	1.15	1.46	4.26
Percentiles	Q_1	37.9	8.3	2.7	6.4	14.35
	Q_2	39.9	9.6	4.1	7.5	17.65
	Q_3	41.7	10.75	4.85	8.6	20.8
Statistic for controlling the normal distribution		0.81	0.13	0.15	0.1	0.4

Table II.5 - Statistics of the hip part measurements by SPSS, cm

		Primary data			Additional data
		T_G	H_{SL}	T_{SL}	Cr_{SL}
Descriptives	Min.	44.6	19.8	30.3	27.95
	Max.	66.7	26	40.6	35.95
	Mean	54.18	22.52	35.1	32.33
	S.D., ±	4.01	1.6	2.52	2.1
Percentiles	Q_1	53.13	21	32.08	28.4
	Q_2	55.25	22.05	36.3	33.8
	Q_3	58.03	23.4	40.2	34
Statistic for controlling the normal distribution		0.15	0.4	0.85	0.77

Table II.6 - Examples of male body from small to large

S^-/SS	*S^-/MM*	*S^-/LS*
		
S^+/SS	*S^+/MM*	*M/LS*
		
M/MM	*L/SL*	*L/ML*
		

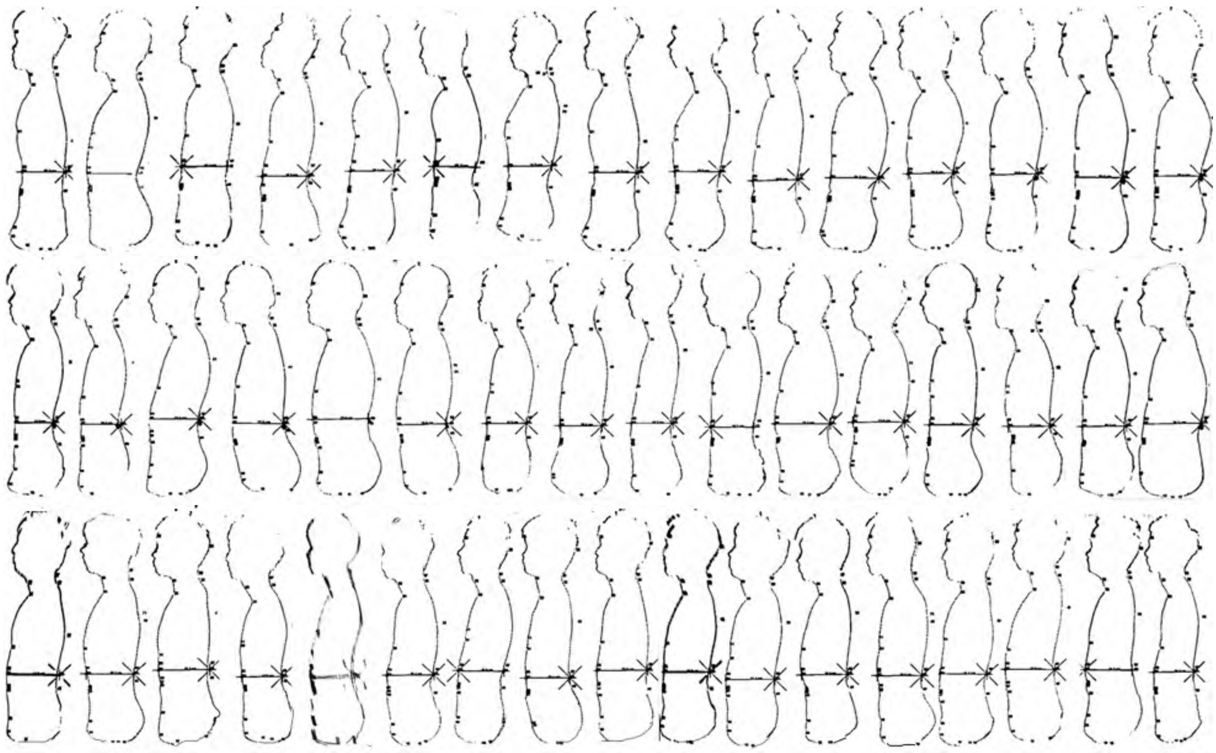


Figure II.2 – Profile sections of bodies' torso

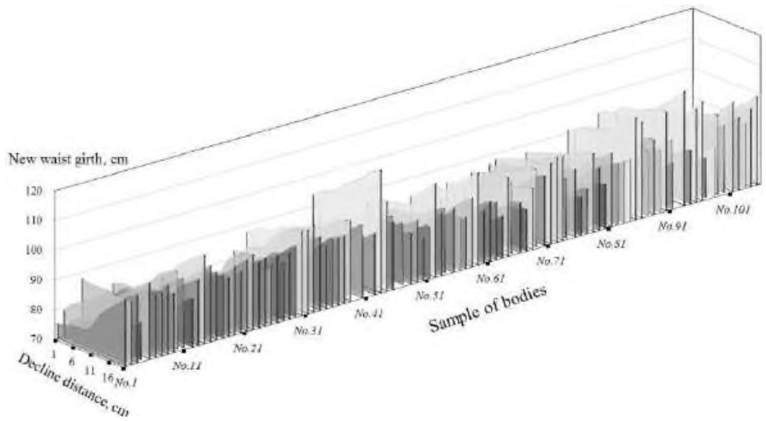


Figure II.3 – New waist girth from -1 to -20 cm below natural waist level, cm

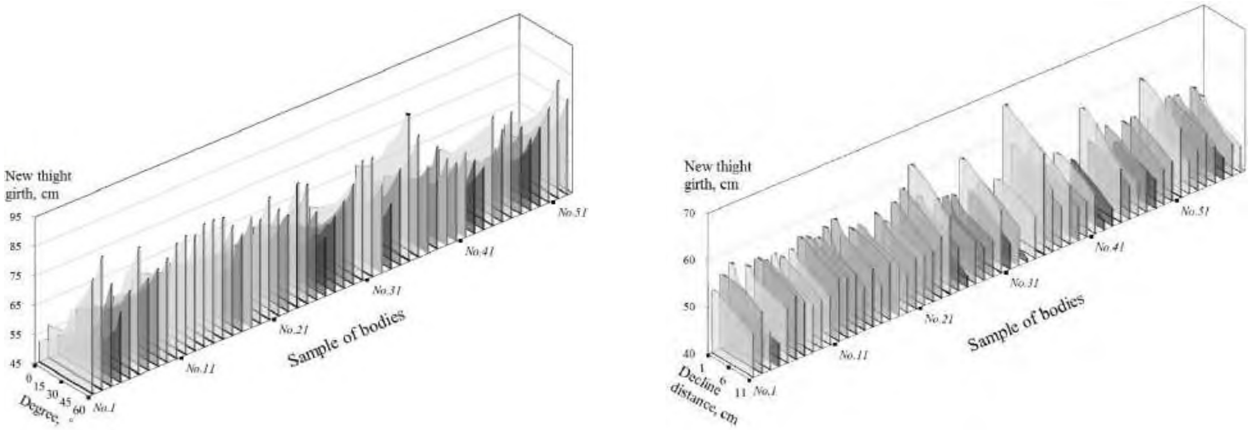
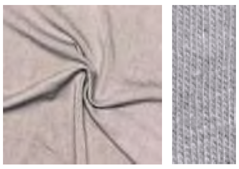
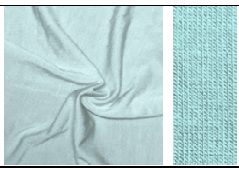
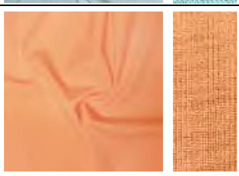


Figure II.4 – New thigh girth at 0 to 60 degree and from -1 to -10 cm

APPENDIX III

Male body pressure test results and knitted materials elongation results

Table III.1 Underwear knitted materials $T_1 \dots T_{18}$

No.	Sample / enlarged	Contents %	Structure	Density, g/cm^2
1	2	3	4	5
T1		**40** combed long-staple cotton (*40s*), **30** combed flax, **25** Lyocell **5** spandex (*20D*) mixed	Single rib, warp knit (Pique)	170 … 180
T2		**50** Acrylic (*32s/1*), **45** Lenzing Viscose® **5** spandex (*30D*) mixed	Interlock rib, weft knit	350 … 360
T3		**92** combed Lenzing Modal® (*80s/1*), **8** Asahi Kasei® spandex (*20D*)	Interlock rib, weft knit	300
T4		**30** combed flax (*70s/2*), **65** long-staple cotton **5** spandex (*20D*) mixed	Single rib, weft knit	170 … 180
T5		**45** Lenzing Modal®, **10** combed cotton (*40s*), **45** cotton (*32s*)	Single rib, warp knit (Pique)	170 … 180
T6		**47** combed cotton (*40s*), **47** Lenzing Modal®, **6** spandex (*20D*)	Single rib, weft knit	110 … 120
T7		**93** Lenzing micro Modal® (*50s*) **7** Lycra® (*20D*)	Single rib, weft knit	165 … 170
T8		**65** Lenzing micro Modal® (*60s*) **35** Asahi Kasei® spandex (*20D*)	Interlock rib, weft knit	170 … 180

Finish table III.1

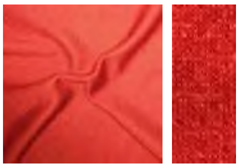
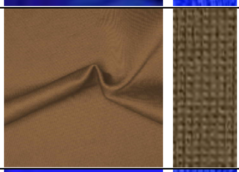
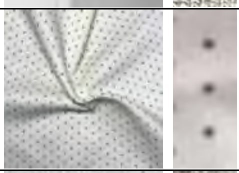
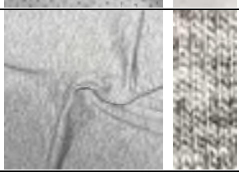
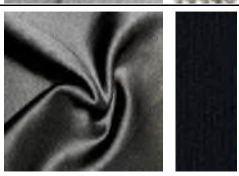
1	2	3	4	5
T9		Coolmax® (*60s*)/combing silver-ion (*100D/144F* draw textured yarn) mixed	Double layer, mesh plain	150 … 160
T10		**75** Lenzing micro Modal® (*60s*) **20** long-staple cotton (*80s*) **5** spandex (*20D*)	Single rib, weft knit	200 … 210
T11		**97** polyethylene, **3** spandex	Single rib, weft knit	170 … 180
T12		**60** Viscose®, **35** polyamide, **5** spandex	Interlock plain	200 … 210
T13		**90** polyethylene, **10** spandex	Single rib, weft knit	260 … 270
T14		**60** Viscose®, **35** polyamide, **5** spandex	Interlock plain	170 … 180
T15		**95** Viscose®, **5** spandex	Plain, weft knit	160 … 170
T16		**100** cotton	Plain, warp knit	200 … 210
T17		**82** cotton, **15** polyester, **3** spandex	Single rib, weft knit	200 … 210
T18		**95** polyethylene, **5** spandex	Plain, Double knit, warp and weft knit	260 … 270

Table III.2 Nomenclature of indicators measured by the KES-F system

Device	Description	Characteristic
1	2	3
KES-FB1 (Shear)	Shear stiffness(rigidity), the slope of the shear stress curve between shear angles of 0.5…2.5° and -0.5…-2.5°	*G*, gf/cm·°
	Elasticity for minute shear, initial difference between shear stress in deformation and recovery, at 0,5… -0,5°	*2HG*, gf/cm
	Elasticity for large shear, at 5… -5°	*2HG5*, gf/cm
KES-FB1 (Tensile)	Linearity of the stress/strain curve, the area under the extension curve during deformation compared to the area of triangle given by the maximum tensile force and the maximum extension	*LT*, -
	Tensile energy (work done in extending the fabric), the area under the extension curve in deformation	*WT*, gf·cm/cm^2
	Recoverability of fabric, the area under extension curve during recovery as a percentage of work of extension	*RT*, %
	Percentage elongation at a set load, max. extension at 500 gf/cm as a percentage of the original sample length	*EMT*, %
KES-FB3 (Compression)	Linearity of compression stress/strain curve	*LC*, -
	Work was done in compressing the fabric	*WC*, gf·cm/cm^2
	Compressive resilience of the fabric	*RC*, %
	Fabric thickness under the pressure 0,5 gf/cm^2	T_0, mm
	Fabric thickness under the pressure 50 gf/cm^2	T_M, mm
KES-FB4 (Surface)	Frictional coefficient	*MIU*, -
	Mean deviation of coefficient of friction (Fluctuation of the frictional coefficient)	*MMD*, -
	Surface roughness	*SMD*, µ

Table III.3 – Average pressure value on mannequin, kPa

Place of pressure measurement (Fig.4.1)	Pressure, kPa, under stretched material, %							*Mean*
	10	*15*	*20*	*25*	*30*	*35*	*40*	
P1, P1′	0.215	0.761	1.471	1.671	2.162	3.923	4.728	2.133
P3, P3′	0.611	1.198	1.834	2.588	2.746	3.124	4.500	2.372
P5, P5′	0.180	0.696	1.942	2.256	3.128	3.696	5.604	2.500
P2, P2′	0.583	0.771	0.998	1.062	1.400	1.513	1.716	1.149
P4, P4′	0.162	0.718	1.227	1.920	2.228	3.180	3.377	1.830
P6, P6′	0.231	0.678	1.023	1.583	1.696	2.382	2.802	1.485
Mean	0.330	0.804	1.416	1.847	2.227	2.970	3.788	-

Table III.4 – Average (materials) pressure value on body, kPa

No.	P_{max}. Warp/weft, kPa						
	Upper arm	Lower arm	Waist	Waistband	Hip	Thigh	Calf
1	2	3	4	5	6	7	8
T1	2.00	2.10	2.15	2.00	1.72	2.05	2.10
	2.05	1.91	2.19	2.10	1.74	2.15	2.05
T2	2.38	2.59	2.38	2.43	1.91	2.43	2.24
	2.34	2.34	2.57	2.53	1.92	2.24	2.29
T3	2.29	2.24	2.29	2.19	1.53	2.33	2.34
	1.72	1.76	2.10	2.15	0.93	1.95	2.10
T4	1.91	2.05	1.91	1.86	0.92	1.86	2.19
	1.95	1.72	1.76	2.10	0.90	2.05	1.95
T5	2.05	2.00	1.86	1.91	0.88	1.86	1.91
	2.10	1.95	1.15	1.97	1.01	1.72	1.45
T6	2.24	2.10	1.05	2.10	0.97	1.11	1.43
	2.10	1.95	1.15	1.97	1.01	1.72	1.45
T7	0.72	0.43	0.86	0.97	0.57	0.57	0.29
	0.96	0.68	1.11	0.82	1.22	0.53	0.82
T8	0.43	0.29	1.00	0.72	0.36	0.57	0.43
	1.14	0.43	0.57	0.86	0.50	0.57	0.71
T9	2.59	2.16	2.14	2.25	1.49	2.07	2.46
	2.30	2.04	2.08	2.19	1.40	1.85	2.35
T10	0.57	0.57	0.72	1.42	0.72	1.00	0.43
	1.27	1.07	1.22	1.16	0.72	1.00	1.42
T11	2.14	2.19	1.96	1.64	1.64	1.96	2.19
	1.83	2.39	1.68	1.73	1.21	1.73	2.15
T12	2.57	2.57	1.86	1.86	1.72	1.89	1.72
	2.25	2.41	1.65	1.55	1.64	1.69	1.70
T13	2.24	2.50	1.55	1.42	1.14	1.24	1.66
	2.12	2.14	1.29	1.23	1.72	1.43	1.92
T14	1.91	1.86	2.00	1.86	1.43	1.86	2.19
	1.95	1.70	1.75	1.29	1.20	1.82	2.19

Table III.5 – Average (materials) elongation value on body, kPa

No.	E_{max}. Warp/weft, kPa						
	Upper arm	Lower arm	Waist	Waistband	Hip	Thigh	Calf
1	2	3	4	5	6	7	8
T1	-16.7 -16.7	-16.7 -16.7	-16.7 -16.7	-16.7 -18.3	-18.3 -16.7	-16.7 -18.3	-18.3 -17.2
T2	-13.3 -15.0	-13.3 -15.0	-13.3 -16.7	-15.0 -16.7	-15.0 -15.0	-13.3 -15.0	-15.0 -15.6
T3	-15.0 -16.7	-15.0 -18.3	-18.3 -18.3	-18.3 -20.0	-20.0 -18.3	-18.3 -16.7	-20.0 -18.1
T4	-16.7 -16.7	-16.7 -16.7	-15.0 -18.3	-15.0 -20.0	-18.3 -20.0	-15.0 -18.3	-18.3 -18.3
T5	-15.0 -18.3	-15.0 -15.0	-15.0 -20.0	-20.0 -20.0	-25.0 -16.7	-20.0 -16.7	-18.3 -17.8
T6	-16.7 -18.3	-16.7 -16.7	-16.7 -16.7	-25.0 -18.3	-30.0 -30.0	-15.0 -18.3	-16.7 -17.8
T7	-20.0 -25.0	-20.0 -20.0	-20.0 -20.0	-25.0 -25.0	-25.0 -30.0	-20.0 -20.0	-20.0 -20.0
T8	-20.0 -25.0	-18.3 -20.0	-20.0 -20.0	-20.0 -20.0	-25.0 -30.0	-20.0 -25.0	-20.0 -18.3
T9	-16.7 -16.7	-15.0 -16.7	-15.0 -18.3	-15.0 -18.3	-18.3 -20.0	-16.7 -20.0	-15.0 -15.0
T10	-25.0 -25.0	-20.0 -25.0	-20.0 -30.0	-20.0 -30.0	-25.0 -30.0	-30.0 -30.0	-20.0 -35.0
T11	-18.3 -20.0	-16.7 -20.0	-18.3 -20.0	-25.0 -20.0	-25.0 -30.0	-20.0 -25.0	-18.3 -20.0
T12	-20.0 -25.0	-16.7 -25.0	-20.0 -25.0	-20.0 -20.0	-25.0 -25.0	-20.0 -25.0	-18.3 -20.0
T13	-18.3 -25.0	-15.0 -20.0	-20.0 -25.0	-20.0 -20.0	-20.0 -25.0	-18.3 -25.0	-18.3 -20.0
T14	-20.0 -20.0	-20.0 -20.0	-20.0 -20.0	-25.0 -25.0	-25.0 -25.0	-20.0 -25.0	-20.0 -20.0

APPENDIX IV

Test results of knitted materials on the KES complex and modeling

Table IV.1 – Underwear compositions of international and Chinese brands

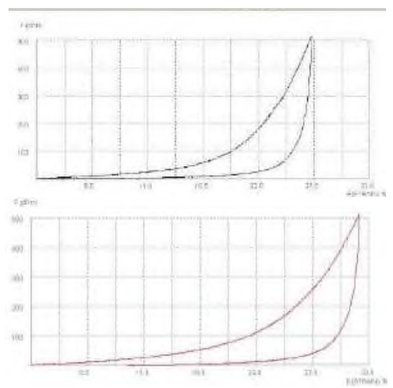
Brand	Composition, %	Brand	Composition, %
Unico	93 Cotton / Nylon, 7 Spandex; 46 Cotton, 45 Nylon, 9 Spandex	I'd	47 Cotton, 47 Modal, 6 Spandex; 95 Modal, 5 Spandex
2(x)ist	90...95 Cotton, 5...10 Spandex; 96 Modal, 4 Spandex	Septwolves	95 Cotton / Modal, 5 Spandex
BOSS	95 Cotton, 5 Spandex	Miiow	95 Cotton / Viscose, 5 Spandex
PUMP!	94...96 Cotton, 4...6 Spandex	Threegun	93…95 Cotton / Viscose, 5...7 Spandex
Diesel	94...97 Cotton, 3...6 Spandex; 57 Cotton, 38 Nylon, 5 Spandex	Your Sun	100 Cotton; 95 Viscose, 5 Spandex
Jockey	90...95 Modal, 5 To 10 Spandex; 48 Cotton, 48 Modal, 4 Spandex	Jianjiang	47 Cotton, 46 Viscose, 7 Spandex 93 Viscose, 7 Spandex; 100 Cotton
HOM	45 Modal, 44 Cotton, 11 Spandex; 95 Cotton, 5 Spandex	Langsha	95 Viscose, 5 Spandex； 100 Cotton
Calvin Klein	49 Cotton, 43 Nylon, 8 Spandex; 82 Polyester, 18 Spandex	Nanjiren	95 Cotton , 5 Spandex
Emporio Armani	49 Cotton, 41 Nylon, 11 Spandex 95 Cotton, 5 Spandex	Aimu	95 Modal, 5 Spandex
C-IN2	94...100 Cotton, 0...6 Spandex; 90...95 Modal / Viscose, 5 To 10 Spandex	Hongdou	95 Cotton / Viscose, 5 Spandex

Table IV.2 Indexes of materials average results by KES-FB (Warp/Weft)

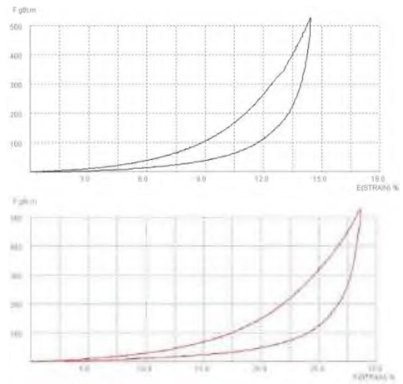
Item	*T1*	*T2*	*T3*	*T4*	*T5*	*T6*	*T7*	*T8*	*T9*	*T10*	*T11*	*T12*	*T13*	*T14*	*T15*	*T16*	*T17*	*T18*
G	0.550	0.498	0.796	0.488	0.436	0.350	0.147	0.121	0.192	0.230	0.265	0.030	0.240	0.120	0.270	0.265	0.480	0.030
	0.548	0.424	0.906	0.502	0.476	0.350	0.103	0.112	0.186	0.280	0.235	0.080	0.240	0.100	0.340	0.235	0.390	0.080
2HG	1.522	0.866	1.392	1.372	1.532	0.656	0.357	0.283	0.429	0.030	0.388	0.550	0.250	0.250	0.600	0.388	1.150	0.550
	1.664	0.848	1.970	1.246	1.698	0.622	0.328	0.275	0.364	0.130	0.050	0.350	0.110	0.150	1.000	0.050	0.980	0.350
2HG5	1.502	0.988	1.574	1.432	1.488	0.644	0.307	0.282	0.429	0.200	0.050	0.550	0.400	0.200	0.630	0.050	1.230	0.550
	1.598	0.906	1.710	1.282	1.698	0.614	0.295	0.269	0.401	0.300	0.205	0.380	0.280	0.130	0.980	0.205	1.030	0.380
LT	0.411	0.501	0.493	0.460	0.451	0.430	0.953	1.165	1.202	0.775	0.775	0.662	0.713	0.687	1.074	0.775	0.611	0.662
	0.423	0.457	0.657	0.445	0.406	0.433	0.963	1.092	1.129	0.795	0.784	0.570	0.742	0.584	1.250	0.784	0.567	0.570
WT	28.050	18.330	23.340	28.900	28.050	27.390	3.650	2.250	2.370	199.700	184.300	104.300	185.000	178.400	7.600	184.300	24.663	104.300
	23.730	32.810	30.230	38.960	29.180	34.630	4.100	5.350	5.520	142.000	137.500	112.300	192.700	165.700	8.100	137.500	43.525	112.300
RT	27.270	48.440	38.510	27.850	31.470	41.910	72.600	64.440	61.180	36.250	38.250	39.730	50.760	78.450	69.740	38.250	45.550	39.730
	23.560	45.070	49.870	21.020	20.170	34.200	68.290	60.750	63.010	37.890	39.640	41.590	46.190	72.970	64.560	39.640	43.858	41.590
EMT	27.280	23.080	40.800	25.110	31.380	25.370	145.650	104.450	15.770	106.070	96.920	105.050	103.750	141.200	28.300	96.920	16.148	63.050
	31.650	27.830	52.840	40.930	32.640	32.080	195.060	127.620	38.950	125.440	70.710	102.860	103.940	165.700	46.840	70.170	30.743	78.860

Finish of table IV.2

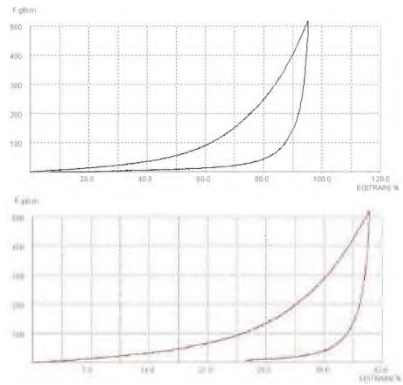
Item	*T1*	*T2*	*T3*	*T4*	*T5*	*T6*	*T7*	*T8*	*T9*	*T10*
LC	0.336	0.389	0.309	0.327	0.354	0.331	0.298	0.317	0.399	0.286
WC	0.272	0.309	0.170	0.213	0.256	0.232	0.277	0.249	0.256	0.250
RC	42.40	54.01	56.96	33.95	39.56	51.23	50.699	56.341	50.931	47.581
T_0	0.861	1.151	0.872	0.783	0.840	0.761	0.708	0.701	0.891	0.616
T_M	0.538	0.834	0.648	0.510	0.550	0.480	0.433	0.477	0.591	0.4179
MIU	0.194	0.252	0.206	0.194	0.334	0.247	0.249	0.233	0.243	0.232
	0.205	0.217	0.191	0.325	0.224	0.210	0.255	0.286	0.282	0.159
MMD	0.009	0.011	0.014	0.012	0.023	0.014	0.011	0.007	0.015	0.016
	0.012	0.008	0.007	0.027	0.012	0.008	0.008	0.015	0.020	0.007
SMD	4.388	3.258	2.516	1.957	8.479	2.503	1.185	0.958	4.666	1.112
	4.275	1.576	1.540	3.808	6.006	2.488	2.003	2.758	4.823	0.853



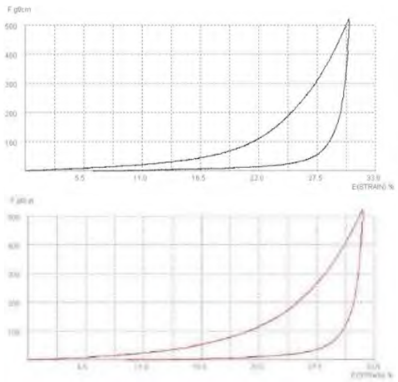
T1



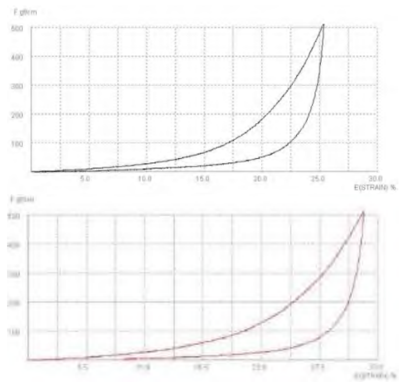
T2



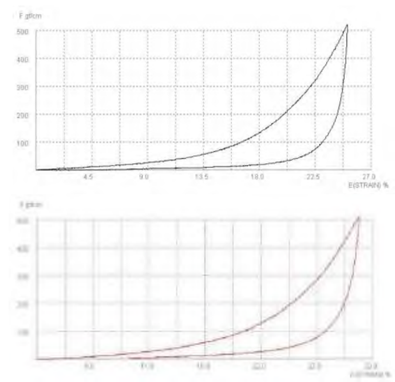
T3



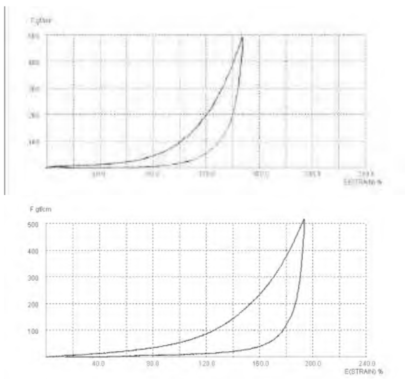
T4



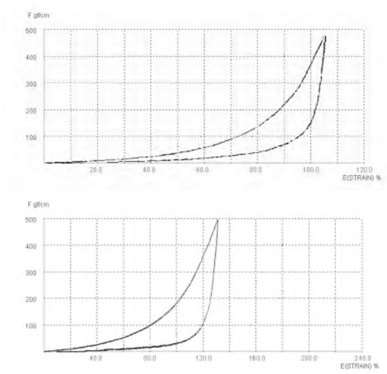
T5



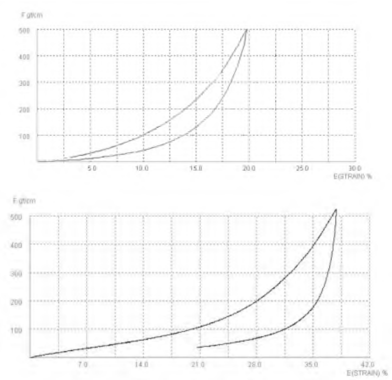
T6



T7



T8



T9

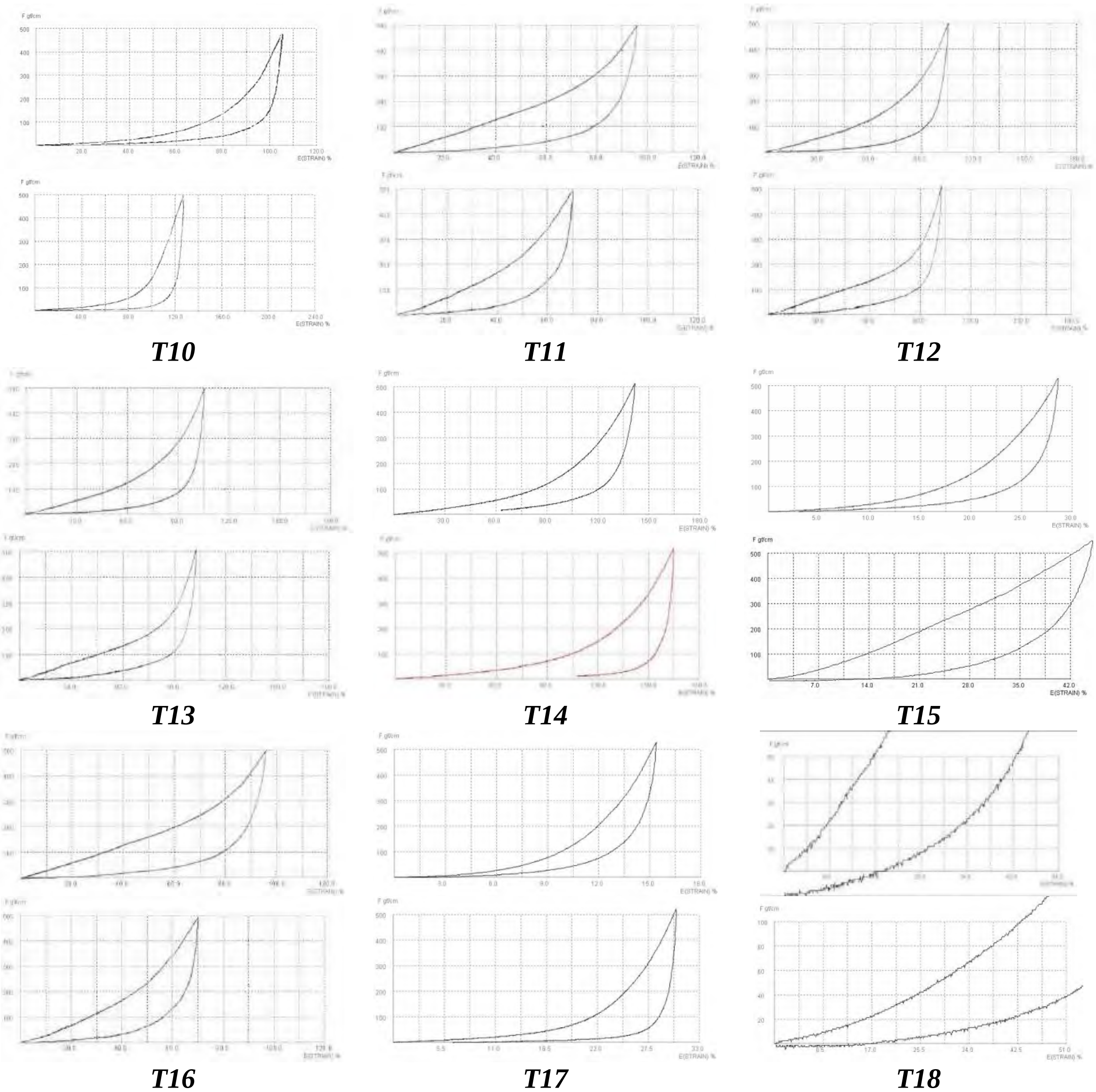


Figure IV.1 – Graphs of testing materials under uniaxial tension on KES device (screenshots of graphical dependencies "tensile force F - relative elongation E" for materials *T1-T18* in the two directions, upper warp / lower weft)

Table IV.3 – “Tension F” of the materials (*E* under 20% and E_{max}). *Warp/weft*, gf/cm

No.	*F*(*5*)	*F*(*8*)	*F*(*11*)	*F*(*14*)	*F*(*17*)	*F*(*20*)	$F(E_{max})$
1	2	3	4	5	6	7	8
T1	10.99	17.10	26.87	40.30	64.73	117.24	87.93
	8.56	17.27	26.50	38.67	56.86	89.38	61.89
T2	25.41	73.03	190.21	448.50	-	-	448.50
	11.03	20.36	34.50	59.41	96.12	154.11	81.05
T3	24.65	36.89	50.78	63.67	80.05	101.05	83.74
	17.71	28.67	38.84	49.86	59.06	71.58	63.71
T4	13.43	23.51	37.86	62.59	110.53	200.60	99.69
	8.08	16.33	22.98	32.61	43.70	59.00	46.45
T5	7.40	12.69	18.53	29.45	42.51	65.60	66.79
	6.38	12.35	21.64	33.34	51.69	77.68	55.58
T6	11.80	20.76	34.61	58.22	101.37	187.27	177.28
	8.76	18.30	28.84	42.12	63.03	93.20	67.37
T7	1.82	2.40	3.64	4.72	6.12	6.78	6.45
	1.76	2.14	3.29	3.92	4.69	6.61	6.12
T8	6.03	7.92	12.07	15.56	18.73	21.59	20.95
	1.59	2.58	3.57	4.76	5.95	7.14	6.95
T9	11.91	42.07	84.14	141.82	-	-	195.42
	14.29	30.16	68.26	82.55	115.85	161.59	125.48
T10	3.77	4.76	7.14	9.33	11.33	13.50	15.82
	4.17	6.35	8.33	10.32	12.70	14.68	14.88
T11	9.12	14.68	20.63	22.78	35.32	43.26	44.45
	14.29	25.79	34.53	45.24	56.36	71.44	83.87
T12	13.49	19.05	21.42	26.19	30.23	33.79	33.79
	19.45	25.74	31.18	36.29	41.73	47.83	55.30
T13	8.9	16.7	30.2	46.8	86.5	93.1	92.8
	11.2	18.0	31.0	42.9	57.2	77.0	92.3
T14	5.22	8.53	12.63	15.41	18.72	22.91	23.48
	3.05	4.99	7.38	9.84	12.49	14.60	17.20
T15	3.14	4.87	5.4	6.98	9.18	10.32	-
	2.24	3.97	4.50	5.46	7.02	8.17	-
T16	11.13	20.64	28.56	46.04	55.63	85.73	-
	5.61	6.75	8.73	11.13	12.78	14.29	-
T17	7.14	7.93	11.37	15.87	20.63	22.25	-
	6.49	6.58	7.11	9.92	11.25	13.89	-
T18	3.97	7.15	16.6	20.64	23.81	32.94	-
	1.49	2.31	4.59	9.33	8.93	10.42	-

Table IV.4 – Materials (10*10 cm) maximum test elongation and shrinkage (warp/weft),%

No.	Max. test elongation, %	Max. shrinkage, %	*No.*	Max. test elongation, %	Max. shrinkage, %
T_1	15/15	10/10	T_{11}	15/15	2/2
T_2	15/15	8/4	T_{12}	25/25	36/24
T_3	15/10	2/0	T_{13}	25/15	2/0
T_4	15/15	4/6	T_{14}	15/15	2/4
T_5	15/10	10/0	T_{15}	20/20	6/6
T_6	15/15	2/0	T_{16}	20/10	4/0
T_7	15/25	30/10	T_{17}	20/25	10/6
T_8	20/20	20/16	T_{18}	10/15	2/0
T_9	25/20	6/6	*Mean*	18.06/16.94	9.00/5.33
T_{10}	25/20	6/2			

Table IV.5 – Correlations coefficient, upper is the Pearson *r*/ lower is *sig.* (2-tailed)
"bold" strong correlation, * *at significant level 0.1,* ** *at significant level 0.05*

Index	Warp			Weft		
	CP	P_{max}	$E_{max.warp}$	*CP*	P_{max}	$E_{max.weft}$
F(5)	**.759**** *.002*	**.708**** *.005*	**-.737**** *.003*	.495 *.072*	**.621*** *.018*	.003 *.992*
F(8)	**.813**** *.000*	**.685**** *.007*	**-.845**** *.000*	**.610*** *.021*	**.701**** *.005*	-.176 *.546*
F(11)	**.742**** *.002*	**.577*** *.031*	**-.797**** *.001*	**.610*** *.021*	**.648*** *.012*	-.267 *.356*
F(14)	**.688**** *.007*	**.507** *.064*	**-.746**** *.002*	**.677**** *.008*	**.686**** *.007*	-.357 *.210*
F(17)	.472 *.121*	.432 *.161*	**-.662*** *.019*	**.718**** *.004*	**.690**** *.006*	-.452 *.105*
F(20)	.448 *.144*	.393 *.207*	**-.666*** *.018*	**.747**** *.002*	**.685**** *.007*	**-.532** *.050*
Fmax.	**.692**** *.009*	**.526** *.065*	**-.774**** *.002*	.496 *.071*	**.543*** *.045*	-.149 *.612*
LT	**-.484** *.079*	**-.514** *.060*	.295 *.306*	**-.492** *.074*	**-.526** *.054*	.436 *.119*
WT	-.238 *.413*	-.034 *.909*	**.533*** *.050*	-.164 *.576*	.052 *.860*	**.538*** *.047*

Finish table IV.5

RT	-.374 *.188*	-.375 *.187*	.300 *.297*	-.314 *.275*	-.297 *.302*	.440 *.116*
EMT	**-.740**** *.002*	**-.604*** *.022*	**.812**** *.000*	**-.774**** *.001*	**-.696**** *.006*	**.798**** *.001*
MIU	-.058 *.874*	-.068 *.852*	.088 *.808*	-.050 *.890*	-.091 *.803*	.165 *.649*
MMD	.152 *.676*	.228 *.526*	.052 *.887*	.151 *.678*	.146 *.686*	-.112 *.758*
SMD	**.507** *.135*	**.542** *.106*	-.427 *.218*	.270 *.450*	.310 *.384*	-.310 *.384*
G	**.595*** *.025*	.492 *.074*	**-.571*** *.033*	**.537*** *.048*	.464 *.095*	**-.705**** *.005*
2HG	**.553*** *.040*	.463 *.095*	**-.600*** *.023*	**.512** *.061*	.425 *.129*	**-.713**** *.004*
2HG5	**.580*** *.030*	.485 *.079*	**-.622*** *.018*	**.537*** *.048*	.446 *.110*	**-.740**** *.002*

Index	*CP*	$P_{\max}$	$E_{\max.warp}$	$E_{\max.weft}$
LC	**.748*** *.013*	**.690*** *.027*	**-.824**** *.003*	**-.698*** *.025*
WC	.055 *.880*	-.070 *.848*	-.135 *.710*	-.078 *.830*
T_0	**.890**** *.001*	**.816**** *.004*	**-.898**** *.000*	**-.829**** *.003*
T_M	**.844**** *.002*	**.768**** *.009*	**-.831**** *.003*	**-.783**** *.007*
RC	-.123 *.736*	-.160 *.658*	.135 *.711*	.240 *.505*

Table IV.6 – SPSS analyses of linear regression

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.800	.640	.595	.305

The independent variable is T0.

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.769	.592	.541	.325

The independent variable is TM.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	1.323	1	1.323	14.228	.005
Residual	.744	8	.093		
Total	2.067	9			

The independent variable is T0.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	1.223	1	1.223	11.594	.009
Residual	.844	8	.105		
Total	2.067	9			

The independent variable is TM.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 / T0	-1.853	.491	-.800	-3.772	.005
(Constant)	2.709	.624		4.344	.002

The dependent variable is ln(Pmax).

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 / TM	-1.028	.302	-.769	-3.405	.009
(Constant)	2.334	.582		4.013	.004

The dependent variable is ln(Pmax).

Sigmoid function (natural exponential function) models (4.4) and (4.5)

Finish table IV.6

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.756	.572	.536	.281

The independent variable is F8warp.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	1.263	1	1.263	16.011	.002
Residual	.947	12	.079		
Total	2.210	13			

The independent variable is F8warp.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
1 / F8warp	-2.924	.731	-.756	-4.001	.002
(Constant)	.721	.102		7.088	.000

The dependent variable is ln(Pmax).

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	.013555

a. Predictors: (Constant), F11warp, EMTwarp, F5warp, LC, T0, TM, F8warp

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.417	7	.488	2656.697	.000[b]
	Residual	.000	2	.000		
	Total	3.417	9			

a. Dependent Variable: Pmax

b. Predictors: (Constant), F11warp, EMTwarp, F5warp, LC, T0, TM, F8warp

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	5.709	.191		29.903	.001
	EMTwarp	-.014	.000	-1.066	-43.962	.001
	LC	-24.964	.760	-1.493	-32.830	.001
	T0	5.159	.182	1.225	28.392	.001
	TM	2.417	.282	.480	8.570	.013
	F5warp	-.181	.006	-2.336	-30.121	.001
	F8warp	.127	.004	4.446	35.713	.001
	F11warp	-.031	.001	-2.851	-36.064	.001

a. Dependent Variable: Pmax

Sigmoid function (natural exponential function) models (4.6) and multivariable liner model (4.7)

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.905	.819	.804	.182

The independent variable is F11.weft.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	1.811	1	1.811	54.482	.000
Residual	.399	12	.033		
Total	2.210	13			

The independent variable is F11.weft.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
1 / F11.weft	-3.886	.526	-.905	-7.381	.000
(Constant)	.765	.065		11.750	.000

The dependent variable is ln(Pmax).

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.913	.834	.820	.175

The independent variable is F20.weft.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	1.842	1	1.842	60.147	.000
Residual	.368	12	.031		
Total	2.210	13			

The independent variable is F20.weft.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
1 / F20.weft	-7.582	.978	-.913	-7.755	.000
(Constant)	.743	.060		12.295	.000

The dependent variable is ln(Pmax).

Sigmoid function (natural exponential function) model (4.8) and (4.9)

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.918	.842	.829	.171

The independent variable is Fmax.weft.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	1.861	1	1.861	63.996	.000
Residual	.349	12	.029		
Total	2.210	13			

The independent variable is Fmax.weft.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
1 / Fmax.weft	-7.404	.926	-.918	-8.000	.000
(Constant)	.750	.059		12.644	.000

The dependent variable is ln(Pmax).

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	.999	.016484

a. Predictors: (Constant), Fmax.weft, TM, EMTweft, F5.weft, T0, F11.weft, F17.weft, F8.weft

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.417	8	.427	1571.830	.020[b]
	Residual	.000	1	.000		
	Total	3.417	9			

a. Dependent Variable: Pmax

b. Predictors: (Constant), Fmax.weft, TM, EMTweft, F5.weft, T0, F11.weft, F17.weft, F8.weft

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	2.990	.184		16.230	.039
	EMTweft	-.019	.001	-1.761	-23.110	.028
	T0	15.983	.637	3.794	25.074	.025
	TM	-23.497	1.058	-4.670	-22.204	.029
	F5.weft	.662	.032	5.560	20.482	.031
	F8.weft	-.446	.024	-7.087	-18.406	.035
	F11.weft	.162	.009	5.088	17.990	.035
	F17.weft	.101	.006	6.006	17.894	.036
	Fmax.weft	-.153	.008	-9.173	-18.374	.035

a. Dependent Variable: Pmax

Sigmoid function (natural exponential function) models (4.10) and multivariable liner model (4.11)

Finish table IV.6

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.822	.676	.635	.364

The independent variable is T0.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	2.213	1	2.213	16.663	.004
Residual	1.062	8	.133		
Total	3.275	9			

The independent variable is T0.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
ln(T0)	2.907	.712	.822	4.082	.004
(Constant)	.148	.028		5.237	.001

The dependent variable is ln(CP).

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.909	.827	.805	.266

The independent variable is SMDwarp.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	2.709	1	2.709	38.236	.000
Residual	.567	8	.071		
Total	3.275	9			

The independent variable is SMDwarp.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 / SMDwarp	-1.704	.276	-.909	-6.184	.000
(Constant)	-1.689	.161		-10.520	.000

The dependent variable is ln(CP).

Power (4.12) and sigmoid function (natural exponential function) models (4.13)

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.835	.697	.672	.289

The independent variable is F8warp.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	2.301	1	2.301	27.592	.000
Residual	1.001	12	.083		
Total	3.302	13			

The independent variable is F8warp.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
ln(F8warp)	.463	.088	.835	5.253	.000
(Constant)	.022	.006		3.887	.002

The dependent variable is ln(CP).

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.875	.765	.746	.254

The independent variable is F20.weft.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	2.527	1	2.527	39.126	.000
Residual	.775	12	.065		
Total	3.302	13			

The independent variable is F20.weft.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
ln(F20.weft)	.397	.064	.875	6.255	.000
(Constant)	.017	.004		3.915	.002

The dependent variable is ln(CP).

Power function models (4.14) and (4.15)

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.932	.869	.852	.057

The independent variable is T0.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	.171	1	.171	53.003	.000
Residual	.026	8	.003		
Total	.197	9			

The independent variable is T0.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 / T0	.666	.091	.932	7.280	.000
(Constant)	2.068	.116		17.810	.000

The dependent variable is ln(Ewarp).

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.900	.810	.794	.060

The independent variable is EMTweft.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	.187	1	.187	51.242	.000
Residual	.044	12	.004		
Total	.230	13			

The independent variable is EMTweft.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 / EMTweft	-10.789	1.507	-.900	-7.158	.000
(Constant)	3.191	.032		99.116	.000

The dependent variable is ln(Eweft).

Sigmoid function(natural exponential function) model (4.16) and (4.1)

Finish table IV.6

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.898[a]	.806	.781	1.26080
2	.948[b]	.899	.870	.97305

a. Predictors: (Constant), T0

b. Predictors: (Constant), T0, EMTwarp

c. Dependent Variable: Ewarp

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	52.688	1	52.688	33.145	.000[b]
	Residual	12.717	8	1.590		
	Total	65.405	9			
2	Regression	58.777	2	29.389	31.039	.000[c]
	Residual	6.628	7	.947		
	Total	65.405	9			

a. Dependent Variable: Ewarp

b. Predictors: (Constant), T0

c. Predictors: (Constant), T0, EMTwarp

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	31.943	2.385		13.393	.000
	T0	-16.543	2.873	-.898	-5.757	.000
2	(Constant)	26.754	2.753		9.720	.000
	T0	-11.761	2.911	-.638	-4.040	.005
	EMTwarp	.023	.009	.401	2.536	.039

a. Dependent Variable: Ewarp

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.892[a]	.796	.771	1.13168
2	.956[b]	.913	.888	.79007

a. Predictors: (Constant), EMTweft

b. Predictors: (Constant), EMTweft, T0

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	39.979	1	39.979	31.217	.001[b]
	Residual	10.246	8	1.281		
	Total	50.225	9			
2	Regression	45.855	2	22.928	36.730	.000[c]
	Residual	4.370	7	.624		
	Total	50.225	9			

a. Dependent Variable: Eweft

b. Predictors: (Constant), EMTweft

c. Predictors: (Constant), EMTweft, T0

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	16.480	.582		28.314	.000
	EMTweft	.036	.007	.892	5.587	.001
2	(Constant)	23.118	2.201		10.501	.000
	EMTweft	.025	.006	.613	4.260	.004
	T0	-7.131	2.324	-.441	-3.068	.018

a. Dependent Variable: Eweft

Multivariable liner models (4.18) and (4.19)

Table IV.7 – Frequencies of equations

		4.4	*4.5*	*4.6*	*4.7*	*4.8*	*4.9*	*4.10*	*4.11*	*4.12*	*4.13*	*4.14*	*4.15*	*4.16*	*4.17*	*4.18*	*4.19*
Mean		-0.04	-0.04	-0.05	-0.09	-0.02	-0.03	-0.02	0.29	0.00	0.00	0.00	0.00	-0.65	-1.18	-0.03	0.92
Std. Error of Mean		0.12	0.13	0.08	0.12	0.06	0.06	0.06	0.07	0.01	0.01	0.00	0.01	0.46	0.39	0.31	0.46
Median		-0.21	-0.13	-0.16	0.03	0.01	-0.01	0.00	0.24	-0.01	0.00	0.00	0.00	-0.77	-1.24	0.11	0.20
Std. Deviation		0.38	0.41	0.31	0.37	0.23	0.22	0.22	0.23	0.03	0.03	0.02	0.02	1.45	1.45	1.15	1.73
Variance		0.14	0.17	0.10	0.13	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00	2.10	2.10	1.33	3.00
Skewness		1.06	0.81	1.81	-3.14	-0.40	-0.30	-0.09	1.20	1.48	0.25	0.16	0.64	1.08	-0.35	-0.23	1.18
Std. Error of Skewness		0.69	0.69	0.60	0.69	0.60	0.60	0.60	0.69	0.69	0.69	0.60	0.60	0.69	0.60	-0.60	0.60
Kurtosis		-0.47	-0.53	3.90	9.92	-0.35	-0.01	-0.65	0.82	1.94	1.20	0.12	0.72	2.22	-0.10	-0.60	1.32
Std. Error of Kurtosis		1.33	1.33	1.15	1.33	1.15	1.15	1.15	1.33	1.33	1.33	1.15	1.15	1.33	1.15	-105	1.15
Percentiles	*25*	-0.29	-0.40	-0.23	0.01	-0.18	-0.19	-0.19	0.13	-0.02	-0.02	-0.01	-0.02	-1.63	-1.85	-1.02	0.01
	50	-0.21	-0.13	-0.16	0.03	0.01	-0.01	0.00	0.24	-0.01	0.00	0.00	0.00	-0.77	-1.24	0.11	0.20
	75	0.37	0.30	0.17	0.04	0.13	0.11	0.13	0.40	0.02	0.01	0.01	0.01	-0.02	-0.25	0.72	2.27

Table IV.8 – Mean result of equations recalculated

Equations of $\hat{P}$	Δ, kPa	δ, %	S.D., ±	Variance	Kurtosis	Skewness
1	2	3	4	5	6	7
(4.4)	-0.037	4.08	0.380	0.144	-0.469	1.062
(4.5)	-0.039	4.82	0.413	0.171	-0.534	0.808
(4.6)	-0.047	4.79	0.308	0.095	3.895	1.809
(4.7)	-0.030	2.27	**0.020**	0.134	4.096	1.736
(4.8)	**-0.021**	**-0.72**	0.227	0.051	-0.349	-0.399
(4.9)	-0.031	1.77	0.221	**0.049**	-0.005	-0.304
(4.10)	**-0.020**	**-0.80**	0.216	**0.047**	-0.652	-0.088
(4.11)	0.294	23.66	0.228	0.052	0.817	1.200
Euqations of $\widehat{CP}$	Δ, kPa/%	δ, %	S.D., ±	Variance	Kurtosis	Skewness
(4.12)	**-0.0016**	5.94	0.029	0.001	1.938	1.482
(4.13)	**-0.0016**	2.99	0.027	0.001	1.195	0.246
(4.14)	-0.0018	4.07	**0.019**	**0.000**	0.12	0.163
(4.15)	**-0.0016**	**2.87**	0.021	**0.000**	0.72	0.641
Euqations of $\hat{E}$	Δ, %	δ, %	S.D., ±	Variance	Kurtosis	Skewness
(4.16)	-0.652	-3.38	1.450	2.103	2.217	1.079
(4.17)	-1.181	-5.57	1.448	2.096	-0.098	-0.347
(4.18)	**-0.034**	**0.14**	**1.151**	**1.325**	-0.595	-0.232
(4.19)	0.918	4.15	1.732	2.999	1.323	1.180

APPENDIX V

Algorithms for constructing drawings of structures and photographs of the tested types of underwear

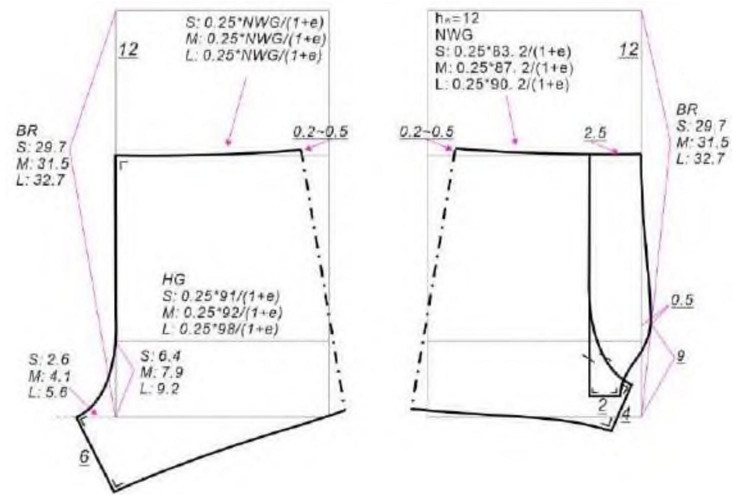
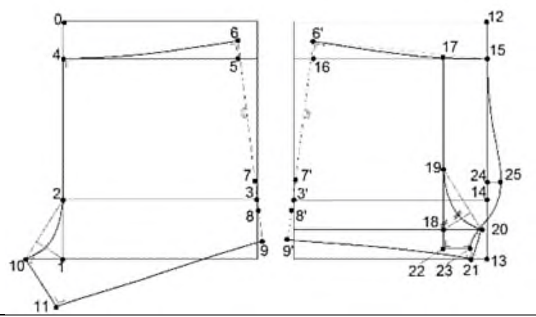


Figure V.1 – the Algorithm of BK (boxers) size M/M (h_W = 12 cm)

Table V.1 – Algorithm of basic designing

Seg-ment	
1	2
0-1	Draw a vertical line from point ***0.*** Distance from nature waistline to crotch level (*BR*).
1-2	Draw a vertical line length of 0.25 · *BR* - 1 (0.25 · *BR* or 0.25 · *BR* + 1), point ***2*** on ***/0-1/***. The position of hip level h_H for S, M and L size type.
2-3	Draw a horizontal line (back width at hip level) length of 0.25 · H_G. **Take account into ease: 0.25 · H_G / c. c is coefficient of the extensibility of material, c = 1 + ease for girth, c ≥ 1; range of ease for girth is 0…23.09%, or take the mean value is 19.48%.*
0-4	Define point ***4*** on the vertical line ***/0-1/***, and plus the width of the waistband below point ***0***. h_W – the underwear style selects the position of the top line as your design, and according to with the location of the top edge of pants, line /*0-4*/ may be located upper or below it.
2-4	Define the length of ***/2-4/***. **Take account of ease: /**2-4**/ / s, s means plus a positive knitted material shrinkage ease on vertical. s is coefficient of the vertical shrinkage when the material extension on horizontal, s = 1 - ease to vertical, s ≤ 1.*

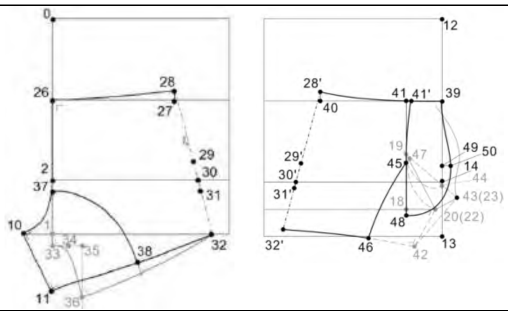
Finish table V.1

1	2
4-5	Draw a horizontal line (back waistband width) length of $0.25 \cdot G_{NW}$. To calculate the G_{NW} for typical male body, this equation of (2.1) can be used $NW_G = 0.02 \cdot h_W{}^2 + 0.61 \cdot h_W - 0.55 + W_G$ **Take account into ease: $0.25 \cdot G_{NW} / c$ + stretch seam, G_{NW} is the new waist girth measured below the nature waistline; stretch seam is the stretch ease value of together with the elastic waistband and underwear body pieces, stretch seam = 0...2 cm; h_W is the distance between the nature waist and top line (new waistline), h_W = **/0-4/**.*
5-6	Define point ***6*** upper ***5*** of $\Delta = \mid (D_{FL} - D_{SL}) \cdot [(16 - h) / 16] \mid$.
6-7	Draw a straight line ***/6-7/*** / *s* = ***/2-4/*** / *s*.
7-8	Draw a straight line ***/7-8/*** = 0.5 · ***/1-2/***.
6-9	Make the straight line (length of underwear side line) of /***6-9***/ = /***6-7***/ + /***7-8***/ + /***8-9***/, from ***6*** through ***7***, ***3*** and ***8*** to ***9.*** And the distance /***8-9***/ selected by underwear type. Ensure the top curve /***4-6***/ with a right angle in ***6***. /***6-9***/ add ease in vertical.
1-10	Draw a horizontal line (back crotch width) to the left. As for mass-produced sizes S, M and L are 2.6, 4.1, 5.6 cm; for customised sizes reference to *ΔWH*.
2-10	Draw a crotch curve of a back center line, connect point ***2*** and ***10***. From ***1*** make a perpendicular line to /***2-10***/. Joint by a curve ***/2-10/*** through the two-thirds of this perpendicular line.
10-11	Draw a straight line inseam. From ***10*** to ***11*** with a right angle between /***10-11***/ and curve /***2-10***/ at ***10***.
11-9	Draw a bottom curve line /***11-9***/. The full thigh length (together with front bottom line length) can be defined by equations (2.2) and (2.3) $NT_G = 81.64 - 0.89 \cdot SL$ or $0.54 \cdot h_T + 54.59$, and make right angles at ***11***, the bottom curve downward (concave up) near ***11*** and upward (concave down) near ***9***.
Seg-ment	Front piece with insert:
12-13	Draw a vertical line /***12-13***/ = /***0-1***/.
13-14	Draw a vertical line of $0.25 \cdot BR - 1$ ($0.25 \cdot BR$ or $0.25 \cdot BR + 1$), point ***2*** on same as /***1-2***/.
3'-14	Draw a horizontal line /***3'-14***/ = /***2-3***/.
12-15	Define point ***15*** make /***12-15***/ = /***0-4***/.
15-16	Draw a horizontal line (back waistband width) length of /***15-16***/ = /***4-5***/.
16-6'	Define point ***16*** upper ***6'*** make /***16-6'***/ = /***5-6***/.
6'-9'	Make the straight line, the same line as in the back pieces (that can design with side seam or without), /***6'-9'***/ = /***6-9***/.
15-17	Define point ***17*** on curve /***6'-15***/, half width of the front insert. /***15-17***/ usually can be designed during 0...6 cm
18-19	Draw the front piece sideline ***/18-19/ = /13-14/***. Draw a vertical line from ***17*** to ***18***, point ***18*** on the horizontal line of median ***/13-14/***.
18-20	Draw a horizontal line (front crotch width) ***/18-20/ = /1-10/***.
19-20	Draw a curve, joint ***19*** and ***20***. The similar way to a back crotch center cure ***/2-10/***.
20-21	Draw a straight line from ***20*** to ***21*** and make a right angle at point ***20***. Ensure the ***/11-10/ = /20-21/ + /22-23/***.

Finish table V.1

1	2
21-9'	Draw the bottom line. Joint ***21*** and ***9'*** and make a right angle at ***21***, the bottom curve upward (concave down) near ***21***. The full thigh length (together with back bottom line length) can be defined by equations (2.2) and (2.3) NT_G = 81.64 - 0.89 · *SL* or 0.54 · h_T + 54.59. Reference different angles and h_T (add negative ease).
17-19	Define the length of */**17-19**/*. **Take account of ease: /**17-19**/ / s, to add positive material shrinkage ease on vertical, s = 1 - ease in vertical, s ≤ 1.*
19-22	Draw a vertical line ***/19-22/*** equal to curve ***/19-20/***.
22-23	Draw a vertical line ***/22-23/*** (1...3 cm), and with right angles at points ***22*** and ***23***. Ensure the ***/11-10/*** = ***/20-21/*** + ***/22-23/***.
13-24	Define the point ***24*** based on h_G. The height of ***24*** depends on the morphological features of body and push-up effect designing. ***/13-24/*** = 0...9 cm, or higher.
24-25	Define the front insert rise, point ***25*** on front center line. In according to *ΔGW*, reference to S, M and L sizes are 0…0.5, 0.5…1.5 and 1.5…3. It depends on morphological features of body and underwear function, for example, for sports underwear it may be less than for daily one.

Table V.2 – Algorithm of boxers designing with the push-up effect

Segment	
1	2
0-1	*BR* = 29.3 cm
1-2	0.3 · *BR* -1 = 7.8 cm
2-30	0.25 · H_G / 1.19 = 19.1 cm
0-26	h_W = 10.5 cm
26-27	0.25 · (0.02 · h_W^2 + 0.58 · h_W + 75.89) / 1.19 + 2 = 19.7 cm
27-28	(D_{FL} - D_{SL}) · [(16 - h_W) / 16] = 0.3 cm
28-29	***/28-29/ = /2-26/ =*** 11.1 cm
29-31	0.5 · */**1-2**/* = 3.9 cm
31-32	h_T = 5 cm (designed value)
1-10	*ΔWH* = 5.5 cm
10-11	7 cm (designed value)
11-38-32	Part of NT_G. The full-size of NT_G = (54.59 - 0.54 · h_T) / 1.19 = 43.6 cm.
37-38	Crotch part back structural seam line. A quarter of crotch piece is ***10***, ***11***, ***38***, ***37***.

Moreover, the seamless back piece's pattern (grey line) as:

2-33	***/2-33/ = /2-10/***
33-35	*/**1-10**/* = 5.5 cm
33-34	0.5 ·*/**1-10**/* = 2.75 cm

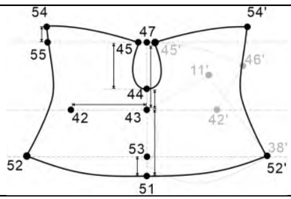
Finish table V.2

1	2
33-36	7 cm. Start as a concave down curve from *33* (this curve should be above 2 ... 3 cm length), then change to straight line to *36* according to with line ***/34-36/***.
36-38-32	Part of NT_G. The length less than ***/11-38-32/***, the full-size of NT_G = (54.59 - 0.54 · h_T) / 1.19 = 43.6 cm, for seamless bottom can add 1 … 2 cm into.

The front and insert (pouch) pieces:

12-13	0.3 · *BR* -1 = 7.8 cm
14-30'	0.25 · H_G / 1.19 = 19.1 cm
12-39	h_W = 10.5 cm
39-40	0.25 · (0.02 · h_W^2 + 0.58 · h_W + 75.89) / 1.19 + 2 = 19.7 cm
40-28'	(D_{FL} - D_{SL}) · [(16 - h_W) / 16] = 0.3 cm
28'-32'	19.9 cm
39-41	4 cm (designed value)
41-41'	0.5 cm (top of insert offset value)
41-45	8.5 cm (***45*** is structural design point)
20-43,	*grey line*, 3 cm, depending on the BPB insert bottom width (part of inseam), in common is 3 cm), ***/20-19/*** is perpendicular to ***/20-43/***.
20-42,	*grey line*, 4 cm (part of front inseam value, ***/20-43/ + /20-42/***= 7 cm)
43-44,	*grey line*, ***/43-44/*** is perpendicular to ***/43-47/*** intersect at point ***44*** (point ***44*** on ***/13-12/***), the right angle at ***43***.
44-45,	*grey line*, Draw a joint curve points ***44*** and ***45***, make a right angle at ***44***. So, ***/42-43-45-46/*** is part of crotch piece original pattern block, wait for the further variant.
42-43,	*grey line*, 8 cm. Draw a line to joint *42 and 43* not through *20*, to make crotch front piece as a reference.
41'-48	***/41'-48/ = /41'-45-44/***
14-49	h_G = 4 cm
49-50	*ΔGW* = 1.5 cm. A bulge at front insert center line ***/39-50-48/***, right angle at ***48***.
45-46	Draw a front structure line to depart front and crotch pieces. ***46*** designed point.

Complete crotch part, draw a vertical line and horizontal lines at first:

Segment	
44-51	***/44-51/ = /44-43/ + /10-37/***. Crotch piece length from front to back.
-	Crotch width wider than */42-42'/*
45-54	***/45-54/ = /45-46/ = /45'-54'/ = /45'-46'/*** = 10 cm (measured length), the structure seam together with front piece.
52-54	Part of bottom length. ***/52-54/*** less than ***/46-42/*** + ***/42-38/***, same as ***/52'-43'/*** less than ***/46'-42'/ + /42'-38'/***. To make bottoms more closely. Make curve middle near to point ***42***.
42-42'	Equal to 16 cm.
45-45'	The width of ***45*** to ***45'*** equal to 2 · ***/45-47/***
45-44-45'	Redraw and smooth curve ***/45-44-45'/***, the length equal to ***/45-44/*** + ***/44-45'/***.
43-51	Equal to the curve ***/10-37/.***
51-53	1 / 3 · ***/43-51/*** = 2.4 cm

Finish table V.2

1	2
52-51-52´	Joint ***52***, ***51***, ***52'*** with a smooth curve, ***/52-52'/ = /38-37/ + /37-38'/***. Depend on the structure seam in back part.
44-45	Equal to ***/48-45/***.
45-47	***/45-47/*** is 0.5 … 1.5 cm. Depend on insert width.
55-54	***/55-54/*** = 1 / 3 · ***/45'-44/***

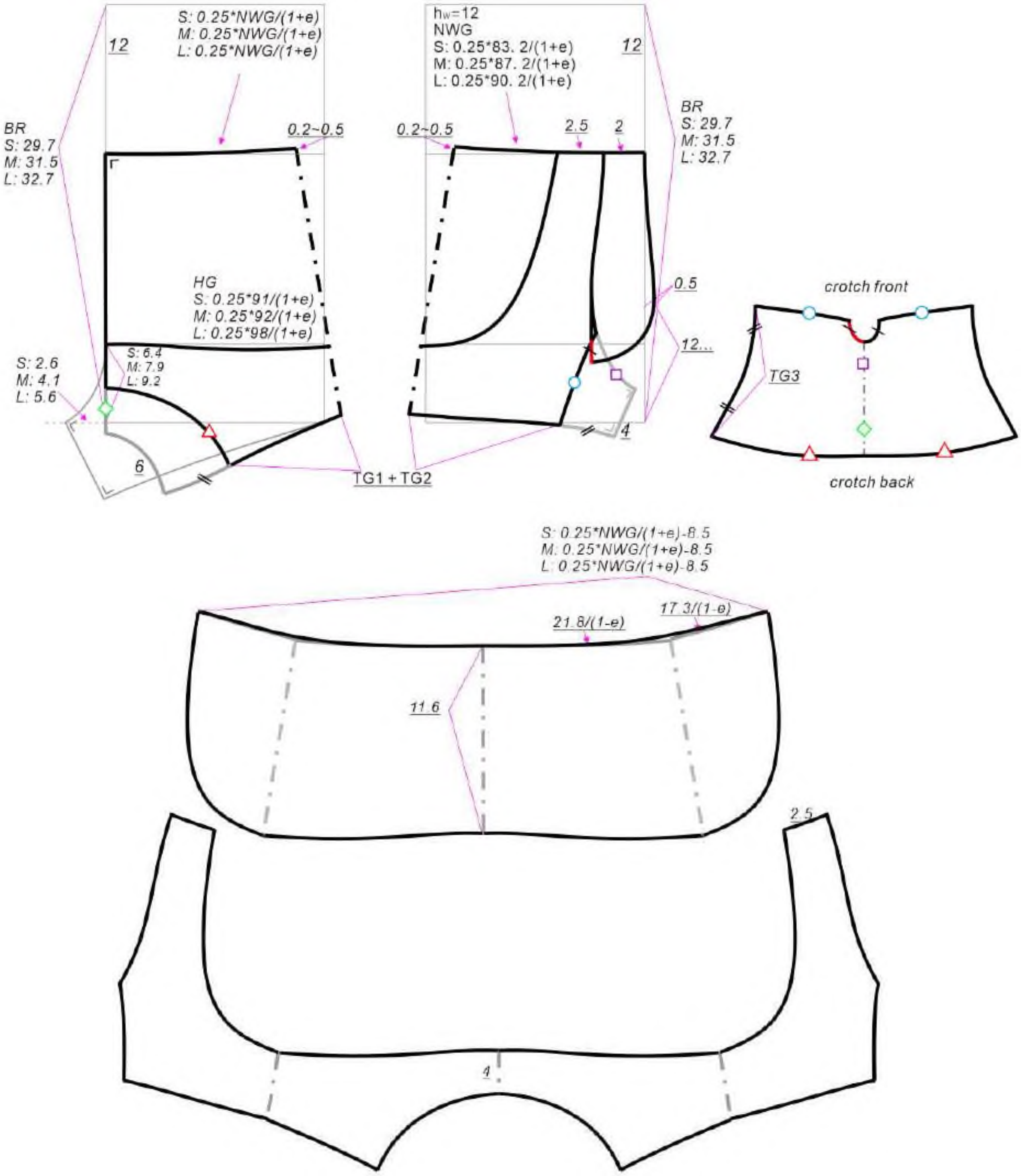


Figure V.2 – Algorithm for a push-up underwear (boxers) size M/M (h_W = 12 cm)

a b

c d

Figure V.3 – Underwear made of 4 kinds materials: a – “U1” with T_1; b – “U2” with T_2; c – “U3” with T_6; d – “U4” with T_{11}

Underwear made of material T_4

Underwear made of material T_1

Underwear made of material T_6 Underwear made of material T_{11}

Figure V.3 – Actions for dynamic try-on

APPENDIX VI

УТВЕРЖДАЮ	УТВЕРЖДАЮ
Директор ZOZH Спортивная марка российской одежды и обуви	И.о. ректора ФГБОУ ВО "Ивановский государственный политехнический университет"
____________ А.В.Мухин	____________ Е.В.Румянцев
"22" февраля 2019 г.	"28" февраля 2019 г.

АКТ производственной проверки результатов, полученных в диссертационной работе Чен Чжэ

Мы, нижеподписавшиеся, конструктор Кутепова М.С., технолог мантрова А.Н. , с одной стороны, и заведующий кафедрой КШИ В.Кузьмичев и аспирант Чен Чжэ, с другой стороны, составили настоящий акт о производственной проверке результатов, полученных при выполнении диссертационной работы "Совершенствование процесса проектирования мужского компрессионного белья".

Дата внедрения - декабрь 2018 - февраль 2019 гг.

Объект внедрения - методика конструирования мужских боксеров II типа.

Условия внедрения - изготовление моделей мужских боксеров из трикотажного полотна Кулирная гладь 30/1 95/5 Хлопок/Эластан в количестве 100 штук

Предприятию были переданы 6 комплектов чертежей 6 размеров

При изготовлении мужских боксеров было использовано оборудование предприятия.

Было выпущено 10000 штук боксеров, которые были реализованы в торговой сети без рекламаций.

ЗАКЛЮЧЕНИЕ. Разработанные чертежи конструкций удовлетворяют требованиям предприятия, а изготовленные образцы обладают высокими потребительскими свойствами.

От ZOZH	От ИВГПУ
Конструктор	Заведующий кафедрой конструирования швейных изделий
____________ Кутепова М.С.	____________ В.Е.Кузьмичев
Технолог	Аспирант
____________ Мантрова А.Н.	____________ Чен Чжэ
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APPENDIX VII
Questionnaire Male consumer preferences

Please mark your choice as √.

1. **Which kind of underwear do you prefer for everyday life?(X_1)**

☐		Briefs Брифы	☐		Bikinis Бикини
☐		Boxer-Shorts (Trunks) Боксерские-Шорты	☐		Jockstraps Стринги-бикини
☐		Boxer-Briefs (slim)Боксерские- Брифы	☐		Thongs (G-string) Ремешок
☐		Boxers (loosely) Боксеры	☐	-	Others
☐	I don't wear underwear				

2. **How many kinds of underwear did you try to wear in your life (please mark each kind)?(X_5)**

☐ Brief (slips)
☐ Hips
☐ Boxers slim
☐ Boxers loosely
☐ String
☐ Jokey
☐ Thongs
☐ Swimming suit

3. **Which style of underwear do you prefer?(X_4)**

☐ Very closely fitting
☐ Closely fitting
☐ Regular
☐ Loosely

4. **Which is your underwear size? (X_6)**

☐ S
☐ M
☐ L
☐ XL
☐ XXL
☐ I don't know

5. Which kind of fabric do you prefer?

☐ 100 % cotton
☐ Cotton + synthetic fibers
☐ Synthetic
☐ With Lycra
☐ All kinds
☐ No preferences

6. Have you changed own preferences about underwear during your life?
- ☐ No
- ☐ Yes

If your preferences changed, can you mark the reason?
- ☐ Because my body morphology was changed in good shape
- ☐ Because my body morphology was changed in bad shape
- ☐ Because my taste was changed
- ☐ Because my income was changed

7. **Which functions of underwear are more important for you? (X_{12})**
- ☐ To feel myself comfortable
- ☐ To have the attractive look when I take off my trousers
- ☐ To improve my body morphology in front
- ☐ To improve my body morphology in back
- ☐ To improve my body morphology in front and back
- ☐ I never think about it, my everyday problems are more serious

8. **Which construction of underwear do you prefer? (X_2)**
- ☐ Seamless
- ☐ With few seams
- ☐ With many seams, especially in front part
- ☐ I don't know

9. Do you like when the underwear push-up your buttock?
- ☐ Yes
- ☐ No

10. Do you like when the underwear push-up your penis?
- ☐ Yes
- ☐ No

11. When you are choosing the underwear for dairy do you think with type of pants (trousers) you will wear together? For example, closely fitting underwear + slim jeans or loosely underwear + baggy pants.
- ☐ Yes, every time I try to adopt the shapes of trousers and underwear
- ☐ No, I am wearing every time one kind of underwear with different trousers (pants)
- ☐ Sometimes I think about the combination, sometimes no

12. **Which a position of underwear waistband do you prefer?(X_3)**
- ☐ Natural waist
- ☐ Below natural waist in 3-5 cm
- ☐ Below natural waist in 6-10 cm
- ☐ Very low

13. **Which a combination of trousers and underwear waistbands do you prefer?(X_{11})**
- ☐ When trousers waistband higher than underwear waistband
- ☐ When trousers waistband lower then underwear waistband

14. Did you meet some problems when the trousers and underwear weren't suitable one to other?
- ☐ No
- ☐ Yes (please write the reason)

15. Do you have the problems when are you buying the underwear?
- ☐ Yes
- ☐ No

16. Which kinds of problems do you meet during your attempt to buy underwear?
- ☐ I don't know my underwear size
- ☐ I don't know which design is more suitable for me
- ☐ I don't how I will look in this kind of underwear
- ☐ Other (please write)

17. Do you ask somebody to help you or ask the opinion of others when you are going to buy underwear?
- ☐ No
- ☐ Yes

18. **Which elements are you checking when buying the underwear?(X_7)**
- ☐ Type (slips, hips, boxers)
- ☐ Color
- ☐ Construction
- ☐ Waistband with brand
- ☐ All elements

19. Which color or pattern of underwear do you prefer?
- ☐ Black
- ☐ Grey
- ☐ Dark blue
- ☐ Red
- ☐ Green
- ☐ White
- ☐ Color blocking
- ☐ Printed
- ☐ Bright color
- ☐ Other (please write)

20. How long do you wear underwear during a day?
- ☐ 24 hours
- ☐ Only in day-time
- ☐ Sometimes I didn't wear underwear in day-time
- ☐ I use other underwear for sleeping
- ☐ I never wear underwear for sleeping

21. **Which problems did meet during the wearing of underwear?(X_{10})**
- ☐ Uncomfortable feeling under fabric influence
- ☐ Uncomfortable feeling under construction influence in crotch area
- ☐ Uncomfortable feeling under construction influence in front area
- ☐ Uncomfortable feeling under construction influence in waistband area
- ☐ Other (please write)

22. Do you think your body morphology need the special design of underwear?
- ☐ No
- ☐ Yes

23. How much underwear for dairy do you have?
- ☐ Smaller than 4
- ☐ 5-7
- ☐ 8-12
- ☐ More than 13
- ☐ I don't know

24. **How often do you buy new underwear? (X_8)**

- ☐ Each month
- ☐ Each half year
- ☐ Each year
- ☐ Evenly

25. **Which brand do you prefer?(X_9)**

- ☐ DIM
- ☐ CK
- ☐ 2xist
- ☐ AndrewChristian
- ☐ BOSS HugoBoss
- ☐ EmporioArmani
- ☐ PUMP!
- ☐ Atlantic
- ☐ Replay
- ☐ Clever
- ☐ Garson Francias
- ☐ Genius
- ☐ Rufskin
- ☐ Timoteo
- ☐ Addicted
- ☐ Other (please write)

26. Which is your age?

- ☐ Teenager
- ☐ 20-25
- ☐ 26-35
- ☐ 36-55
- ☐ More than 55