Three-Dimensional Quantification of Foundation Garment's Shaping Effects

Anke KLEPSER, Stephanie HISS, Angela MAHR-ERHARDT, Simone MORLOCK
Hohenstein Institut fuer Textilinnovation gGmbH, Boennigheim, Germany

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Abstract

Fashion garments sculpt the human body according to the up-to-date style. Foundation garments used to be out of whalebone and stiff materials. Nowadays thin and light shapewear aims to smooth obvious subcutaneous fat. Material, pattern, fit and formability of the body tissue influence the effect of shapewear. Thus, it is not known how much or even if shaping garments effect the body form. Moreover, there is a lack of standardized methods to analyze shaping effects of foundation garments. Up to now research focused two paths to analyze the functionality of shaping garment. First was to quantify the pressure applied, second was to measure the body changes achieved by the products. Governmental funded research project "Shaping Effects" aims to combine and pursue the research approaches. Project term is two years starting from April 2017. Therefore, most of the work is ongoing. The following presents preliminary results. 41 shapewear products were tested with HOSY apparatus to measure pressure gradient. PicoPress device was utilized to determine pressure between garment and manikin or human body respectively. 3D-analysis based on before and after scans was performed to measure changes in body geometry. Two test subjects tested shaping garments so far. Test methods were processed successfully. First results underlined the influence of material properties, body geometry and body tissue on shaping effects.

Keywords: 3d body scanning, foundation garment, shaping, analysis method

1. Introduction

One major aim of garments is to sculpt human body according to the up-to-date fashion style. While in the 1950s female bodies supposed to have an hourglass shape, in the 1980s shoulder pads and oversized jackets transformed women into V-like figures. One important protagonist in the body shaping area is foundation garment. It used to be a corset with whalebone and stiff materials that shaped a wasp waist. Nowadays it is thin and light shapewear with high performance material smoothing obvious subcutaneous fat. The aim is to reduce girths at waist, belly and tights or at least smoothen the silhouette. Thereby, tissue changes caused by age or weight will be diminished.

Material, pattern, fit and formability of the body tissue influence the effect of shapewear. Thus, it is not known how much or even if shaping garments effect the body form. Moreover, there is a lack of standardized methods to analyze shaping effects of foundation garments. Currently the development of shapewear products is characterized by trial and error methods based on fitting tests with subjects to find the optimized balance between shaping or compression and wearing comfort. Besides the visualization of the effects they enable a subjective feedback. Fitting tests are vital within the development process. Thus, they are time consuming and cost-intensive. Valid and reproducible data is strongly needed. New concepts for an objective validation of shaping functionality have to be developed. Research focuses two paths, the quantification of pressure applied by and the measurement of body changes achieved by garments.

1.1. Garment pressure evaluation

Shaping functions like pushing up, smoothing or reducing body areas are achieved due to pressure carried out by the textiles on the human body. Pressure conditions at the clothing body interface are not only responsible for body shaping but also for wearing comfort. Therefore, pressure measurement is an important research topic. Researchers made first steps with pressure measurement systems and 3D-Bodyscanners to investigate the abilities of shapewear. While pressure measurement systems enable to quantify the force textiles apply on the human body, 3D scans visualize the tissue changes. The ergonomic wearing comfort of men's stockings [1], men's suits [2], bras [3], sportswear [4,5], compression textiles for medical applications [6,7] etc. was examined. Tsujisaka et al. (2004), Wang et al. (2011) und Dongsheng et al. (2003) deployed standard pressure sensors (e.g. PicoPress®, Kikuhime, FlexiForce) or internal developments on the base of pneumatic converters [8-10]. The utilized measurement systems are medical devices to analyze pressure values of compression bandages used for the treatment of venous insufficiency or hypertrophic scar formation e.g. Thus, pressure measurements with sensors on the human body are complex. Varying Poisson's ratio at different body tissues as well as torque and shear forces may lead to measurement errors [11]. Moreover, by and by the body tissue is adapted to the shaping of the garment. The findings indicate that selective pressure measurement may not be enough to investigate the functionality and mode of action of shaping products [12]. In recent projects the use of textile sensors was investigated [13-17]. The benefit is a pressure inspection regarding large areas like mattresses or cushions. Stockings to analyze the pressure situation in shoes where developed as well as bicycle saddles. With a textile sensor garment pressure could be evaluated across the entire shaping product. Therefore, sensor garments in different sizes need to be developed that will not affect the fit and functionality of the shaping garment.

The standardized measurement of the pressure gradient applied by medical stockings is in Germany performed by test apparatus compression measurement system Hohenstein (HOSY) [18-20]. It provides pressure values characterizing a circumference at a defined position. Though, some shaping products show pressure zones, in the front or back area respectively. The aim is to shape different body areas in a specific way. The impact of those zones is not measurable by HOSY. Pressure measurements by calculation models have been investigated as well [21-24]. These research projects aim to optimize simulation software for virtual try on processes in the product development. They focus the visualization of material concerning tightfitting or compression garment. The real functionality and mode of action of shaping products need to be investigated to verify the simulation results. Physical methods for integrated qualification methods are to be developed.

The development of so called sensor manikins was the aim of the research of Yu et al. (2004) and Wang et al. (2011) [25,26]. Yu et al. developed a soft manikin on the base of individual body measurements of a test person representing the average dimensions of an Asian woman. Pressure measurement was performed on the soft manikin and on the real person. Though, measurements on flexible areas, like the belly, revealed low values. These results correlated, with measurements on real persons. The findings of Yu et al. indicate that soft body tissue affects pressure measurement. Therefore, garment pressure measurement should rather be analyzed on rigid surfaces. Wang et al. developed a manikin with solid surface and eight integrated sensors. The measurements showed comparable values at each sensor. To enable investigations in different sizes the manikin was enlargeable in breath direction. However, this is scientifically disproved. Analysis of body form changes from one size to the next larger size show that proportions do not increase linearly nor in only one direction [27-29]. Nevertheless, the research work of Wang and Yu is groundbreaking and shows the potential of sensor manikin application in garment pressure evaluation. Hence, sensor measurements describe the pressure garments applied on human bodies. They do not provide the foundation to conclude which body part is shaped and how the geometry changes. This is because garment pressure is just one factor of shaping effects. Body tissue has a great impact on the shaping results. The consistence of human body tissue reacts quite different regarding garment pressure. Thin tissue layers with rigid structures beneath are obviously not that shapeable like soft tissue. Therefore, it is of great interest to investigate not only the forces applied on belly, buttock and hip tissue but moreover the changes of body geometry obtained by shaping garments.

1.2. Analyzing shaping effects with 3D-BodyScanner

Since body scanners are utilized for acquisition of human body data researchers investigate their application in fitting processes [30-37]. The basis is before and after scans, thus test persons in underwear and in specific garments. The scans are merged and differences in geometry can be quantified. This offers a variety of analysis. The advantages of the method are [32]:

- Fast and contact-free acquisition
- Reproducible measurement of extensive body dimensions and detailed 3D fit analysis without the presence of the test person
- Direct comparability by juxtaposition of fittings with differing products, sizes and test persons
- Viewing scans in various perspectives by rotating and zooming functionality
- 3D-analysis of air gaps between body and garment [36,37]
- Simple data storage

Fig. 1. Scans of test garments in German size 38 (bust girth 88cm) with differing widths, cross sections at bust girth, waist girth and hip girth (top down) to investigate distances and contact areas

3D data enables analysis regarding distance between body and garment by generating cross sections on transversal plane (upper and lower segmentation). Cross sections on frontal (front and back segmentation) or sagittal plane (left and right segmentation) provide the possibility to analyze the body silhouette (see figure 1). Liu et al (2007) points out the advantages of this method to investigate shaping effects [33]. The benefit can be drawn in the visual comparison of test persons in regular underwear and shapewear. Liu et al. emphasizes that the loss of color and background facilitates the process. Ernst et al. (2012) pursued the method [34]. They defined three effects: shaping, compressing and smoothing. Shaping effects of garments were investigated by cross section comparison in transversal and sagittal plane. Positive and negative effects were identified. Concave areas at the waist were shaped whereas convex areas at spine were bridged by the material. Ernst et al. defined compressing effects as the reduction of girths. The results show correlation between shaping effects and age or connective tissue respectively. One disadvantage of this method is the deployment of test persons. This may lead to measurement uncertainties. On the one hand human body is subject to weight fluctuations. Subsequently, body measurements vary. On the other hand, it is quite a challenge to reproduce postures in the scanner without variances. Large posture differences may lead to discrepancy in landmark positions. Future research must consider developing a scanning process to reduce postural variability. Schwarz-Müller et al. (2018) introduced a promising approach with a positioning aid [38]. Their research underlines the importance of an acquisition process that will lead to valid and comparable 3D-data. Unfortunately, this has not yet been published by start of the project “Shaping Effects” of which parts will be presented in the following sections. Project term is two years starting from April 2017. Therefore, most of the work is ongoing. The aim of the project is to develop a new quantification method of shaping effects. To achieve this goal a combination of pressure measurement and body change investigation was intended. Thereby, an advancement of the method to analyze shaping effects on base of 3D-scans was targeted.

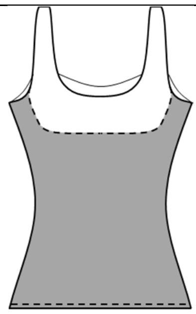
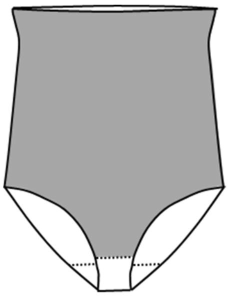
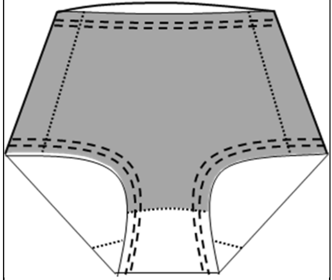
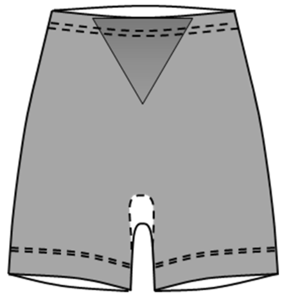
2. Method

Every shapewear product was tested regarding the applied pressure with HOSY apparatus, PicoPress device on manikins and test subjects. The shaping effect was investigated with a 3D-analysis based on before and after full body scans with regular underwear and shapewear.

2.1. Choice of Shapewear

For the development of an analyzing method for shaping effects it was important to use a variety of products. In total 41 products were tested. Incorporated were three shirts, one body, two tights, three slips and three panties all in a small, medium and large size (see table 1). The main focus of the project are the body changes at the waist and hip area. Therefore, one requirement was that the garments should cover and intend to shape at least one of these regions. Slips and panties were present in different shaping levels. Especially the shirts showed particular shaping zones at the waist and upper hip area whereas the material at the bust girth was high elastic and without compressive properties. One slip has a more rigid shaping zone at the product front/belly area. The other garments showed no obvious zones with higher shaping characteristics.

Table 1: Examples of the tested shapewear products

			
shaping shirt	shaping body	shaping slip	shaping panty

2.2. Participants

Six participants were recruited in the German sizes 38 (bust girth 88cm), 42 (bust girth 96cm) and 46 (bust girth 104cm). The product sizes correspond to bust girth 88cm, 96cm and 104cm respectively. The associated measurements were defined in accordance with SizeGERMANY women's size charts [27]. They were distributed between 25 and 49 years, with an average of 41.75 years. The average height was 166.4cm (SD=10.12). The tests with the subjects are ongoing. Currently, they are completed by two participants wearing size 38 and size 42. On the example of these two test subjects the developed method is demonstrated.

2.3. Pressure gradient measurement

To examine the compression gradient of shapewear test apparatus compression measurement system Hohenstein (HOSY) was utilized. It consists of 20 directly following tensile test devices, each

Fig. 2. HOSY test of pressure gradient of functional t-shirt

with a width of 5cm (see figure 2). This enables the apparatus to examine garments with a maximum length of 140cm in almost any shape without destroying them. The garment is fixed in the HOSY in the requested length and is then stretched to the desired circumference. During this process the force performed by the garment in circumference direction is detected. The compression is calculated by the herewith determined force exerted onto the body. The measurement output is in mm mercury (mmHg).

2.4. Pressure measurement on manikins and human bodies

To investigate the pressure values exerted by shapewear on a body form the PicoPress system by Microlab was utilized on manikins, German size 38, 42 and 46, and on test subjects, German size 38 and 42. The aim is to compare pressure measurements on the manikin and on the human body to investigate value differences and identify human tissue impact. PicoPress system is a portable digital gauge for medical purposes. "*A circular transducer made out of an ultra thin biocompatible material in which a known quantity of air is inserted*" is used [39] (see figure 3, on the right). The transducer is placed between body and garment. The detected pressure is measured and visualized by the digital gauge. The measurement output is in mm mercury (mmHg). The advantage of the PicoPress system is, that it become established in the field of compression bandages and was utilized in research projects as well. In addition, it is fast and easy to use.

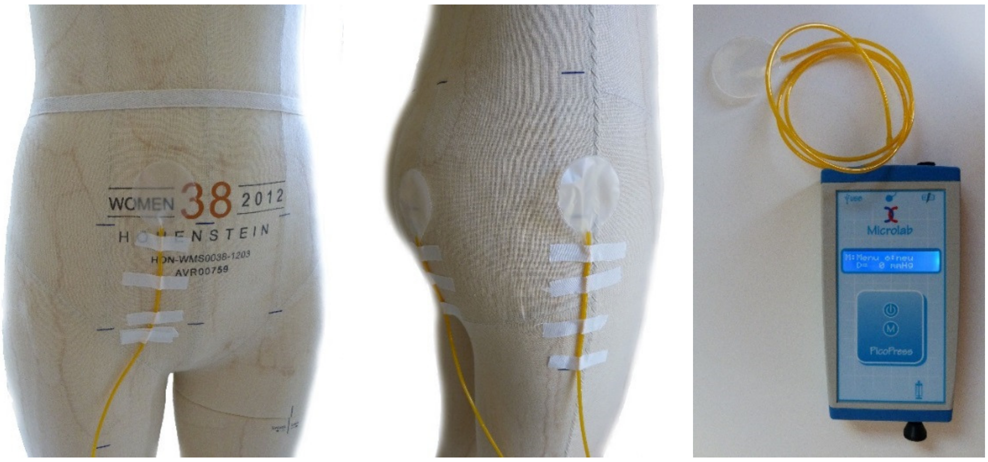


Fig. 3. Pressure measurement on manikin German size 38 (left, middle), system PicoPress (right)

On the manikins and on the human bodies three sensors were placed at defined positions on the right side of waist and hip area: 1. Belly highest point; 2. Hip, greatest width at hip girth; 3. Hip, biggest depth at hip girth (see figure 3, left, middle). Tests showed that the air tubes interfere pressure measurement when they are to close by the sensors. Therefore, air tube layout was defined to be straight lined from the sensor. Depending on the garment products air tubes run originating from the sensor up or downwards. The tubes were fixed by medical tape. Slips in size 38 did not cover sensor position 2 properly. Sensors had to be adjusted about 5cm above the defined position. Shirts in size 42 did not cover sensor position 3 properly. Sensor had to be adjusted about 5cm above the defined position. The intensive application of the pressure system reveled that values vary taking repeated measurements at the same position. This problem could be solved by taking care of equal air distribution in and preventing folds at the sensor.

In addition to the measured pressure values participants were asked for their subjective shaping sensation at the defined positions and in general. They assessed the pressure directly after putting on the shapewear on a scale from one to seven, were one is light shaping and seven is heavy shaping.

2.4. 3D analysis of body shape changes

The main objective of the project was to develop a 3D analysis process to quantify shaping effects. Therefore, before and after scans were performed with the participants, first in regular underwear and second wearing the shaping products. Scans were postprocessed and each scan of shapewear was compared with the reference scan (regular underwear) three dimensionally.

Test persons were recorded with Vitus Smart XXL body scanner [40]. All scans were performed in standard ISO posture: stand upright, legs hip-width apart and arms slightly spread laterally [41]. To generate scans in comparable postures a positioning aid was developed (see figure 4). This enables participants to position their feet in the defined way for each scan similarly. The distance between the feet can be individually adjusted. The setting can be derived from scales.

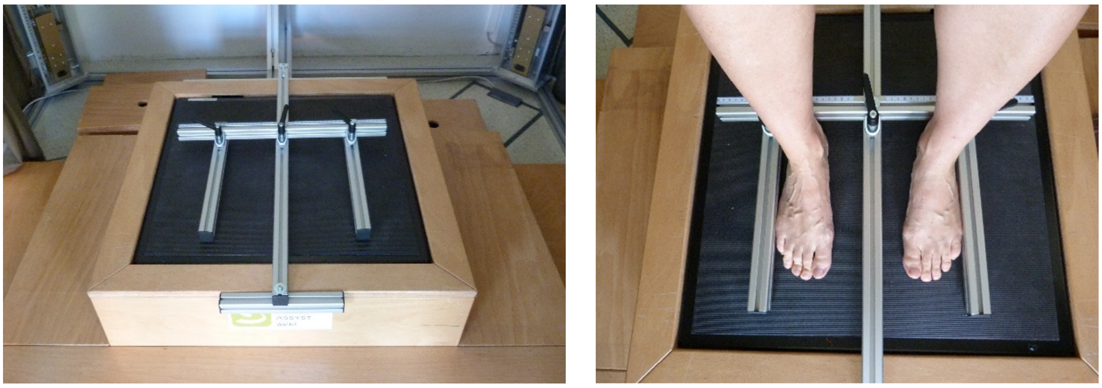


Fig. 4. Positioning aid

Each participant was equipped with a standard bra and a laser cut slip. The standard underwear is worn underneath the shapewear and at the reference scan. Therefore, it should not have any shaping effect on the body. The standard bra was defined for SizeGERMANY sizing survey as being non-forming and supporting the breast in an almost natural shape [27]. The laser cut slips were chosen because of being non-bulky especially at the seams. The test persons were scanned twice with every garment.

Postprocessing of the 3D-data and 3D analysis was performed with Geomagic Studio 2012 [42]. The result of the body scanning is a point cloud that needs to be edited. Four steps were performed: 1. Deleting outliers; 2. Reducing noise; 3. Calculating wrap; 4. Smoothing wrap. Afterwards, scans were segmented into the main focused area. Area of interest was defined from under bust girth down to mid of upper limb (see figure 5).

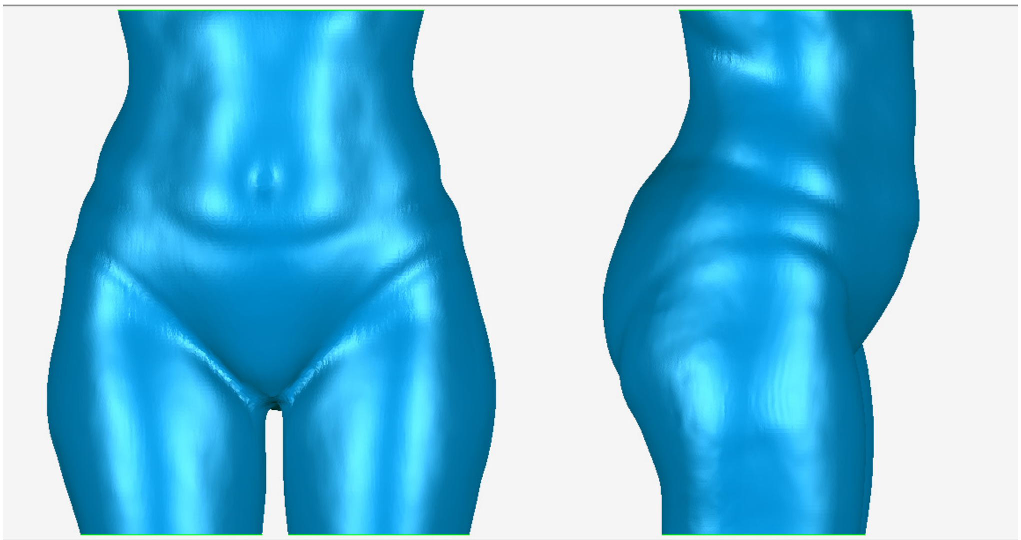


Fig. 5. Body segment waist and hip area in regular underwear

Body measurements hip girth and waist girth are taken from each scan in regular underwear and shapewear and compared. Measurement differences are investigated. Body segments were compared regarding shaping and silhouette smoothing. Shaping was examined by 3D-analysis of body geometry. Therefore, scans in regular underwear and in shapewear product are merged. 3D-analysis was performed, reduction and bridging were visualized with false color. Green represents areas with changes less than 1.0mm. Blue represents areas with reduced body parts and yellow, orange or red represent areas with bridged parts (see figure 6).

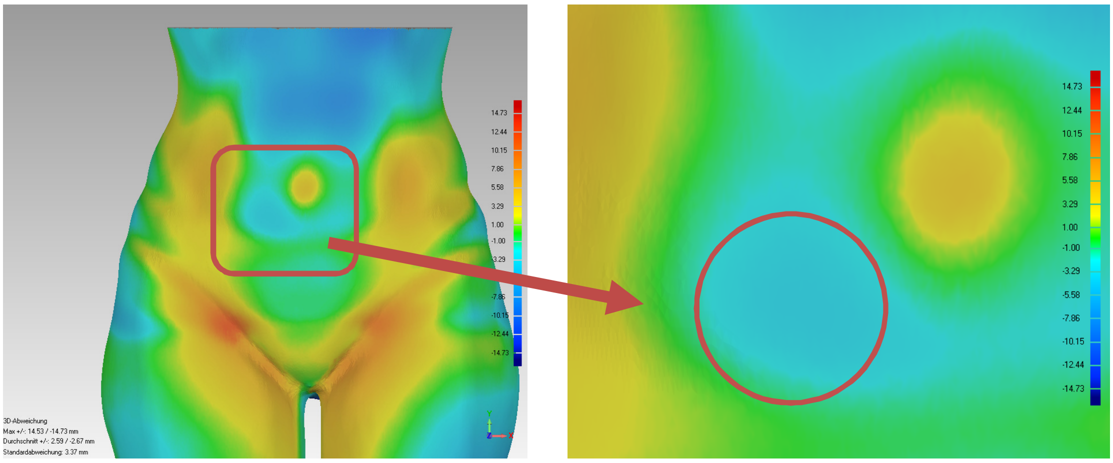


Fig. 6. 3D-analysis of changes of body geometry at belly

The negative (shaping) values at the defined positions (belly, hip and buttock) were identified (see figure 6 right side) and categorized into 5 reduction degrees: 1=equal, 2=light, 3=medium, 4=strong and 5=extra strong (see table 2).

Table 2: shaping effect cluster

Cluster	Reduction degree	Geometry changes [mm]
equal	1	0-1.0
light	2	1.01-5.0
medium	3	5.01-10.0
strong	4	10.01-15.0
extra strong	5	15.01-20.0

Silhouette smoothing was investigated by cross sections in frontal, transversal and sagittal plane (see figure 7). Transversal cross sections were made at waist and hip girth. Merged scans are cut and compared, were the grey line represents the scan in regular underwear and the red line represents the scan in shapewear. Shapewear smoothens bumpy tissue cushions. Changes were identified.

Fig. 7. Cross section analysis of silhouette smoothing in frontal (left) and sagittal (right) plane

3. Results

As noted above the investigations are ongoing. The following results are referring to the analysis of two participants, one with size 38 and one with size 42. Each test (HOSY, pressure measurement on manikins and human bodies, 3D-analysis of changes in body geometry and cross sections) examines factors influencing the shaping effects. Further project steps will be the fusion of the results to examine correlations between the different test methods.

3.1. Pressure gradient measurement

At the two examined girths hip and waist pressure values starting from 1.4mmHg up to 10.9mmHg were measured. The comparison of the sizes revealed differences. The values are decreasing from size to size. The average pressure gradient in size 38 is 4.8mmHg, in size 42 4.0mmHg and in size 46 3.4mmHg. The practical elongation, the difference between the so-called table measurement (product is unstretched and flat on the table) and the according to the defined size stretched garment, is decreasing as well. This means that the garment in the larger sizes is not intended to be stretched that much as the smaller size.

3.2. Pressure measurement on manikins and human bodies

The average values at investigated positions belly, hip and buttock showed differences regarding the manikin size (see Table 3). Pressure is increasing in larger sizes at sensor position "belly" whereas it is decreasing at sensor position "hip" and "buttock". It can be assumed that the specific differences of the body geometry between the sizes leads to these results. Small sizes show a more pronounced curvature with stronger bending at hip and buttock. The belly of size 38 is compared to the other sizes rather flat (see figure 7 and 8). These finding strengthens the assumption of body geometry being one important factor determining the measurable pressure applied on the human body. In addition, even though tailor manikins have a rigid surface some parts are soft to reproduce soft body tissues. Therefore, pressure measurement on these manikins underlie deviation. Future pressure investigations should be performed on rigid manikins. This is part of the project presented and one of the further steps.

Table 3: Average pressure values

	Pressure [mmHg]		
Sensor position	Size 38	Size 42	Size 46
Belly	6,08	6,17	6,83
Hip	10,25	7,75	7,58
Buttock	6,00	6,17	5,42

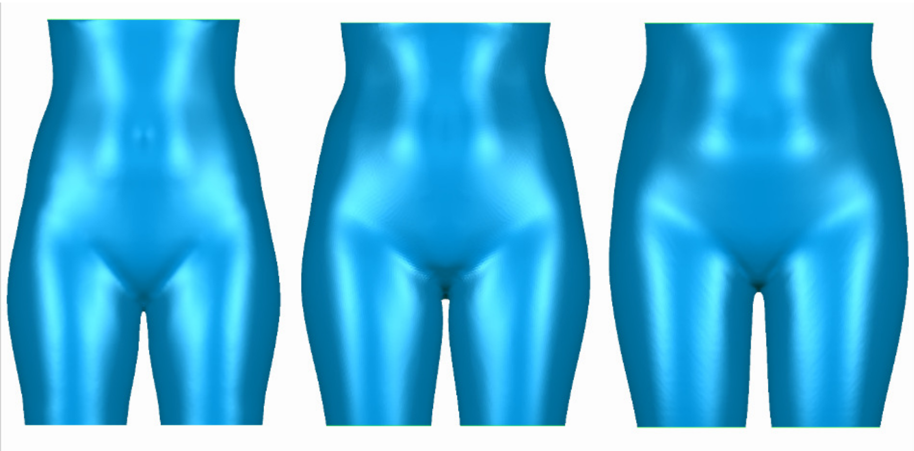


Fig. 7. Manikins in size 38, 42 and 46 (left to right) – front view

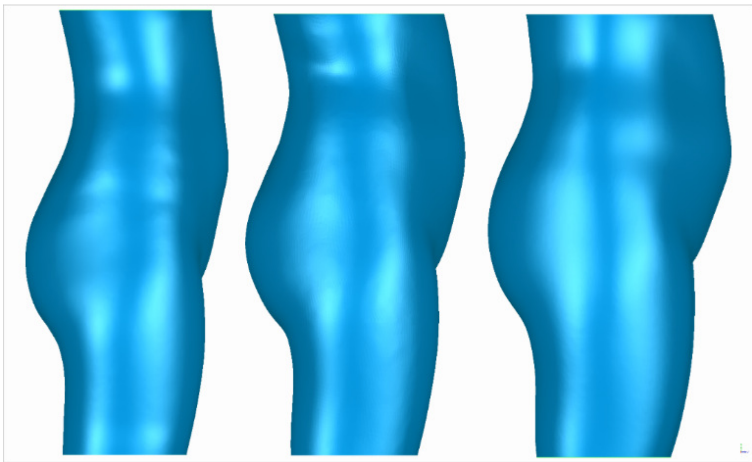


Fig. 8. Manikins in size 38, 42 and 46 (left to right) – side view

Pressure measurement on the human body with PicoPress device was performed with two test persons, one size 38 and one size 42. Both were asked for their subjective shaping sensation as well. Test persons were asked to assess pressure at the same three positions/areas. Thus, it became clear that participants found it difficult to differentiate between the body areas. In the majority of cases they assessed the whole product with one shaping value. The maximum subjective shaping value was 5 (on a scale from 1 to 7). The maximum pressure value measured on a test person was 9mmHg and on a manikin 15mmHg. Despite the small number of participants so far, Pearson ratio was calculated for all three sensor positions for a first glance. Between the subjective shaping sensation and the measured pressure values correlations could not be observed. In contrast, between pressure values on the human body and pressure values on the manikin there was at belly position a slight (r= .536) and at buttock (r= .817) and hip (r= .781) position a strong correlation. These findings have to be reviewed with the results of further test persons. Apart from the calculated correlations it can be concluded, that subjective shaping sensations are complex, hard to differentiate and difficult to assess.

3.3. 3D analysis of body shape changes

Body measurements hip girth and waist girth of test person's scans were taken in regular underwear and shapewear and compared. Hip girth showed an average deviation of 0.89cm. 25% of the shapewear did reduce the hip girth. Waist girth showed an average deviation of -0.14cm. 41.67% of the shapewear did reduce the waist girth. Maximum reduction was waist girth with -2.10cm. The findings indicate that waist area is more shapeable then hip area.

3D-analysis of body changes was performed, and defined positions "belly", "hip" and "buttock" examined regarding the reduction degree from "equal" to "extra strong". Analysis revealed an average reduction degree at position "belly" of 2.42 (SD=0.78), at position "hip" of 2.08 (SD=0.88) and at position "buttock" of 1.29 (SD=0.46). Maximum degree of 4 was measured at "buttock" and "belly". Maximum at "hip" was a reduction degree of 2. These findings strengthen the described circumstance that body areas with thin tissue layers and rigid structures beneath are less shapeable then areas with soft tissue.

Cross section analysis showed bridging, compression and silhouette smoothing. At current status individual product results of a shapewear slip can be shown as an example. Figure 9 shows a cross section at waist girth, were the grey line represents the body in regular underwear and the red line represents the body in a shapewear product. At the spine the body is bridged while the front belly is compressed. This effect is achieved in both sizes.

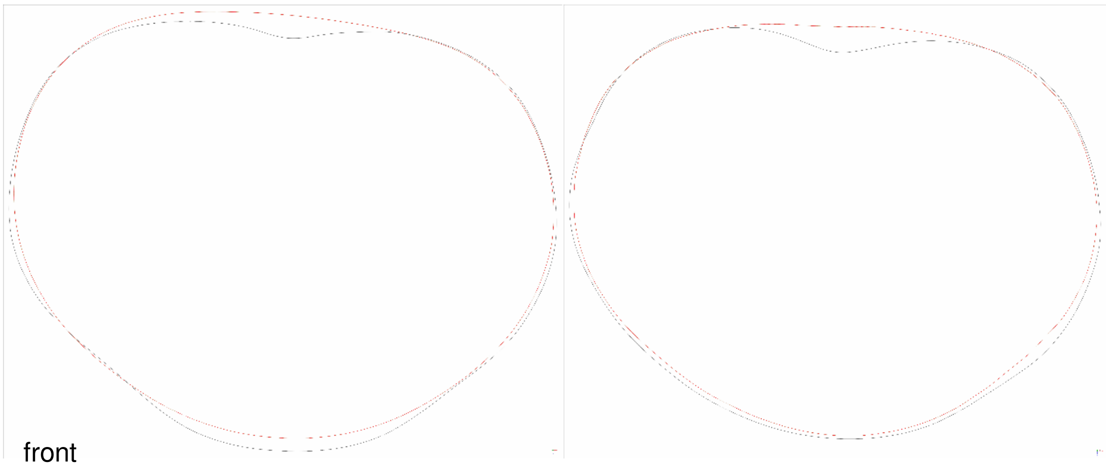


Fig. 9. Cross section as waist girth – size 38 (left), size 42 (right)

Figure 10 shows a cross section at hip girth. Garment is bridging pelvic bones in the front and even some parts of the buttock area. Shaping could not be determined.

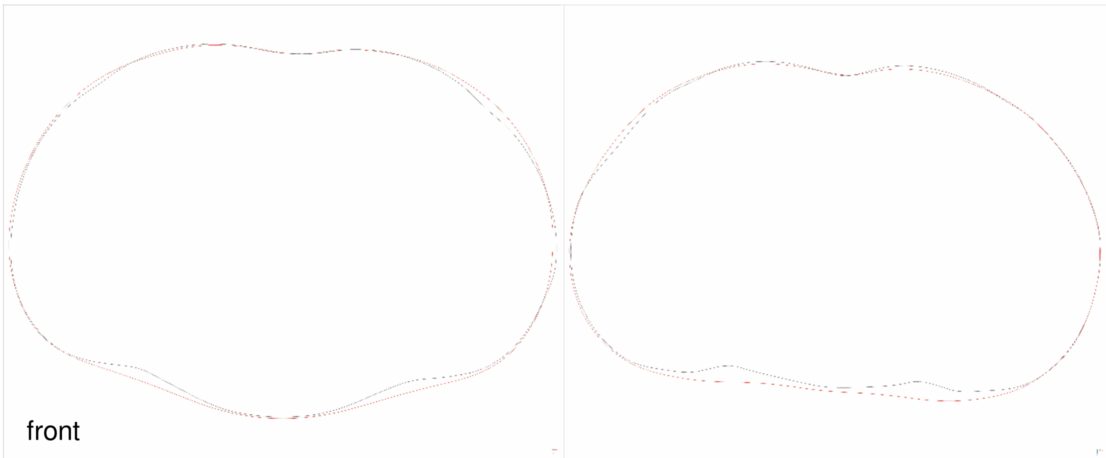


Fig. 10. Cross section as hip girth – size 38 (left), size 42 (right)

The cross section at frontal plane shows silhouette smoothing especially in size 42. The shapewear adjusted bulky tissue at the side of the body (see figure 11). The cross section at sagittal plane reveals again the bridged areas in the front of the body at hip area. The buttock area is smoothed and even lifted in size 42 (see figure 12).

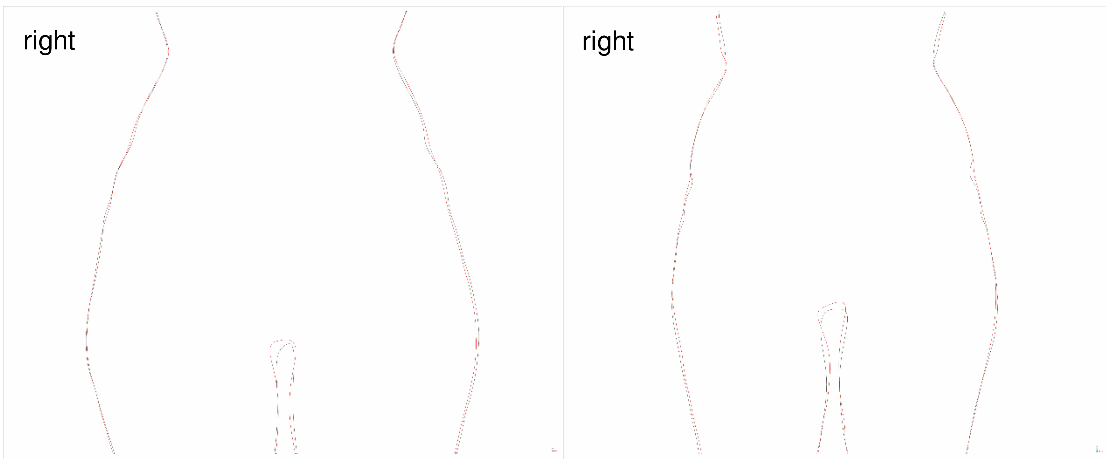


Fig. 11. Cross section at frontal plane – size 38 (left), size 42 (right)

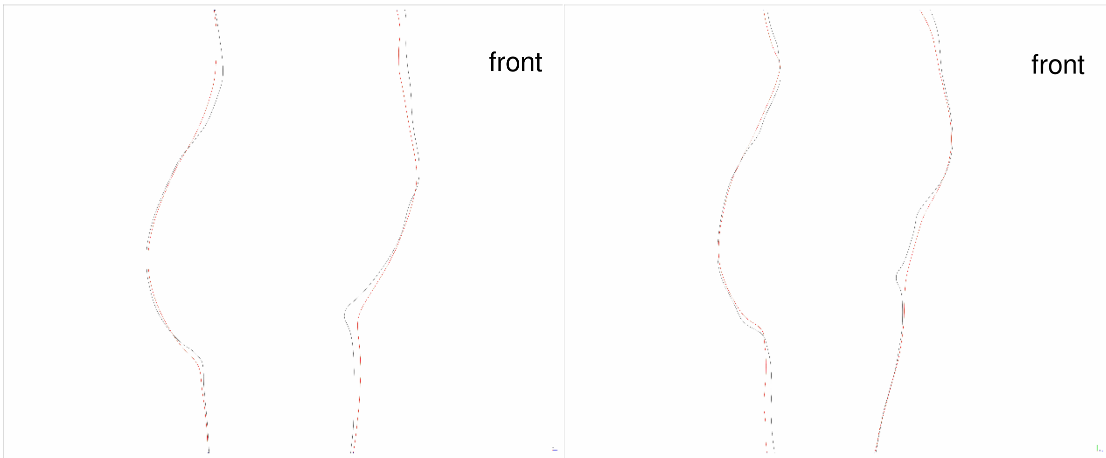


Fig. 12. Cross section at sagittal plane – size 38 (left), size 42 (right)

4. Conclusion

The project aim is to look on shaping effects from different angles. Therefore, different tests were performed to investigate factors influencing the shaping effect. Each analysis provides a component to a comprehensive investigation of shapewear functionality. Body shape, garment pattern and material properties are influencing the shaping effect.

Pressure gradient measurement with the HOSY apparatus showed material parameters like the practical elongation is decreasing from size to size as well as the pressure value itself. It is well known that pressure value increases when material is stretched. Yet, the question is unsolved as to whether for larger sizes a lower or higher pressure value is necessary.

Pressure measurement with the PicoPress device on the manikins in size 38, 42 and 46 showed decreasing values at the hip and buttock sensor position but increasing values at belly. This underlines the impact of the body geometry on the pressure applied by shaping garments. Yet, tailor manikins have soft areas which leads to measurement inaccuracy. Therefore, a manikin with rigid surface is built for further investigations. Pressure measurements on human bodies seam to correlate with the data collected on the manikins.

The subjective assessment of shaping effects by participants is complex. They found it rather difficult to differentiate between the pressure sensation at the defined areas. The first interviews indicate that assessment of shapewear functionality based on test subjects requires further considerations to create valid data.

The 3D-analysis of body changes strengthens the research finding that body areas with thin tissue layers and rigid structures beneath are less shapeable then areas with soft tissue. And finally, cross section analysis showed the described bridging, compression and silhouette smoothing by shaping products. Still, further test of the reduction degree assessment must demonstrate whether it leads to a distinction of the changes in body geometry. The cross section analysis is visual so far. Thus, a quantification method needs to be developed.

After the further development of the individual test methods, the last research step will be the combination of it. This will lead to a comprehensive quantification method for shapewear. Yet, the need for additional research is already evident. The amount of test subjects needs to be expanded to create a stable database.

5. Acknowledgment

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