Chapter 4

CASP Methodology for Virtual Prototyping of Garments for People with Postural Disorders and Spinal Deformities

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Additional information is available at the end of the chapter

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Abstract

"Nobody is Perfect" is a phrase we often hear and use for different purposes. It can relate to our physical appearances or behavioral properties. A great share of the world's population is faced with difficulties caused by postural disorders and spinal deformities. In our chapter we are not dealing with medical points of view. Instead, our intention is to highlight the problems and needs of affected people for suitable, well-fitted, and attractive garments. It is a fact that they need clothing items, not only for everyday use but also for special, festive occasions and sports. Finding suitable garments can be a nightmare for them. Normally, ready-made garments cannot be used if the postural disorders and spinal deformities are very expressive. Therefore, an individual approach is needed for planning, designing, and producing such garments. We propose virtual prototyping and CASP methodology for analyzing digitized geometry supported by computer-aided pattern designs for designing suitable, well-fitted garments for people with postural disorders and spinal deformities. "CASP" stands for Curvature, Acceleration, Symmetry, and Proportionality. It is used for methodology to analyze those four properties on surfaces in a virtual computer environment, as explained further on.

Keywords: CASP methodology, virtual prototyping, garments, postural disorders, spinal deformities

1. Introduction

Postural disorders and spinal deformities present major difficulties for affected people, not only from the medical point of view but also from the point of view of finding appropriate clothing. Without doubt, it can be stated that assuring garments with perfect fit and functionality taking into account the increased need for a modern design is not possible without an extensive use of modern computer-based technologies, above all three-dimensional (3D) body scanning, computer-aided design, and virtual prototyping. Moreover, additional methods for analyzing digitized geometry, such as CASP (Curvature, Acceleration, Symmetry, and Proportionality), are needed for assuring appropriate garment part designs and final fit of the garment. CASP methodology is a widely applicable approach in fields of use where a 3D virtual model is present. We have used it for virtual prototyping of garments for people with postural disorders and spinal deformities.

Nowadays, we can use virtual reality applications to produce digital prototypes of different garments and other textile forms, especially three-dimensional. The designers can alter their design creations with less time and cost. The aim of 3D virtual prototyping is to build a virtual model instead of developing a real product. Virtual garment prototyping is a technique which involves the application of computer-aided design systems used for the development of the garment pattern designs and the assessment of their fit to the 3D body model and virtual assessment of the appearance of the whole garment.

This chapter presents topics related to the multidisciplinary fields of computer graphics and analysis, 3D scanning, and 3D virtual modeling with the aim of supporting virtual prototyping of garments for people with postural disorders and spinal deformities. Mainly scoliosis and kyphosis are treated, because a significant share of the population is facing these problems, especially in the older population.

As a transformation tool between real world and virtual world, 3D scanning is used to capture and digitize real objects. 3D scans describe an object's shape. It makes sense to use precise 3D scanners for solid and rigid objects, where small details or deviations are important and can be measured, but for virtual prototyping, it is usually enough to have a rough shape of a person. Live persons are moving and changing shape literally with every breath and heart beat. Therefore, it is better to perform low-detail scans.

In this chapter, we present research relating to the applicability of CASP methodology to nonstandard body figures' garment pattern design with the aim of finding out whether CASP methodology is right for predicting the garment pattern design for persons with a curved spine, as well as for the construction of well-fitted garments.

After the theoretical background and study of the literature dealing with curves and shapes, CASP methodology is introduced and explained. Medical points of view regarding postural disorders and spinal deformities are detailed in order to highlight the need for adapted garment designs. Practical examples are discussed using CASP methodology, including three case studies dealing with curvature graphs, together with two examples related to the design and virtual prototyping of garments for people with postural disorders and spinal deformities. The chapter concludes with suggestions for further studies in this important and interesting research area.

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2. Theoretical backgrounds

The human mind tries to order everything within the environment either in order to see specific patterns or just to try to understand something, as the Gestalt theory explains [1]. This "classification" is performed in every scientific field. The real world can be digitized very easily with 3D scanners and transformed into a virtual computer environment. Hence, it is important to treat 3D scans with proper tools for analysis or any further geometry extraction. To begin with, curves have already been explored widely and discussed; therefore, it is important to introduce a number of works from this field in the following paragraphs.

Curves with aesthetic impression are parts of logarithmic graphs [2–4], which have logarithmic horizontal axes with steps like 0.1/1/10/100/1000/10,000, and so on. The researchers in Ref. [2] observed graph curvature (K) in dependence of path (s)—K(s) in the logarithmic curvature histogram (LCH). They defined an aesthetic curve as a curve whose LCH is a straight line.

Researchers Kanaya et al. [3] used this method to determine objects' impressions by analyzing sections on objects' surfaces. They found that observed objects with Japanese origin have the so-called convergent impression and objects with European origin divergent impression. The word "convergent" comes from the graph in which the chart curve nears the horizontal line. Contrarily, "divergent" means a graph with a chart curve that goes away from the horizontal line. The authors provided a CAD system (computer-aided design system), which can feel the same impression on curved surfaces as those that human designers can. On the base of LCH, they proposed three types of surfaces by human impression: convergent, divergent, and neutral.

The authors Yoshida et al. in Ref. [4] have observed and analyzed spatial aesthetic curve segments drawn with completely mathematical functions. Curvature graphs and LCHs of those curves were plotted, analyzed, and classified.

Giannini, Monti, Podehl, and Piegl were leading researchers who participated in the project FIORES II [5–7]. They proposed several terms for styling properties and features in CAID (computer-aided industrial design. With observation of communication between stylists and engineers and technical meaning, they built a list of terms that describe styling properties; these are [5–7] as follows:

- Radius/blending
- Convex/concave
- Tension
- Straight/flat
- Hollow

- Lead-in
- Soft/sharp
- S-shaped
- Crown
- Hard/crude
- Acceleration

Not all researchers use all terms in their works, and they agree that the list is not complete or perfect. Some of the terms are similar, while some characteristics can be described with several terms [6].

2.1. CASP methodology

We tried to establish and improve the classification, but we developed a completely novel approach instead. Curvature graphs were not the main observation object any more. Rather, we observe the spatial surface, where distances from the created plane to the surface are valuated and collected in four values, which are characteristic for the observed surface. It is named CASP methodology [8]. The four properties that characterize surfaces are as follows:

- Curvature—C,
- Acceleration—A,
- Symmetry—S, and
- Proportionality—P.

Furthermore, combinations of quotients of those values have proven several charts and properties of observed parts of surfaces. CASP methodology is a widely applicable approach in fields of use where a 3D virtual model is present. CASP methodology was performed also on garments for people with postural disorders and spinal deformities.

First, we have to explain the meaning of the four properties.

Curvature goes from − to + sign. Zero determines a neutral curvature and represents a plane. Negative values determine a concave surface and positive values are for convex surfaces, as **Figure 1** shows. Values are calculated as the arithmetic average of normalized $n \times n$ distances, including a preposition sign. They are arranged in the $n \times n$ matrix. The $n \times n$ matrix follows natural directions, and is not the same as in mathematical writing. Mathematically, it has swapped rows over the middle row. The $n \times n$ matrix starts with entry (0,0) at the left bottom corner [8–11].

The starting point on the analyzed surface is also marked at the bottom left side. This enables us to locate the position of the same point in the 3D space and in the $n \times n$ matrix.

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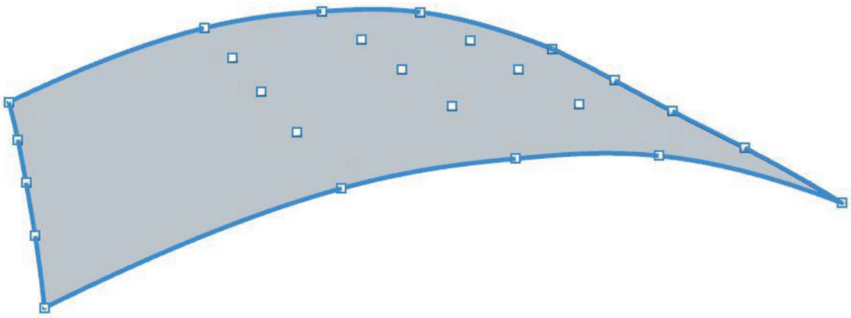

Figure 1. Curvature.

Acceleration is a property observed in a longitudinal direction and has higher values on curves where the curvature changes more. A typical accelerated surface is shown in **Figure 2**.

Symmetry compares the left and right sides of a surface. It takes just positive values. Zero means perfect symmetry of a surface. Values for S are observed over the middle column of the $n \times n$ matrix, as in **Figure 3**. Symmetry can be detected as the arithmetical average of differences between entities' pairs compared over the middle column in the $n \times n$ matrix.

Proportionality is the fourth property to indicate the size or width of the surface. It is calculated as a ratio between the length and width of the observed surface, as shown in **Figure 4**. As described in Ref. [12], it has to be projected on a triangular $n \times n$ plane.

The whole $n \times n$ procedure is based on the use of the graphical algorithm Grasshopper® (GH) [11], which is add-in integrated with the 3D modeling tool Rhinoceros (RH) [12]. Parametrical procedures are created by dragging components onto a canvas. Outputs of these components are then connected to the inputs of subsequent components, and so on. Grasshopper is used mainly to build generative algorithms and it acts like a programming tool. Many of Grasshopper's components create 3D geometry. Procedures may also process other types of algorithms, including numeric, textual, audiovisual or haptic applications. We used GH because of complex algorithms that can be connected and combined easily. Our procedure for analyzing digitized surface geometries exists in 10 steps [8–11].

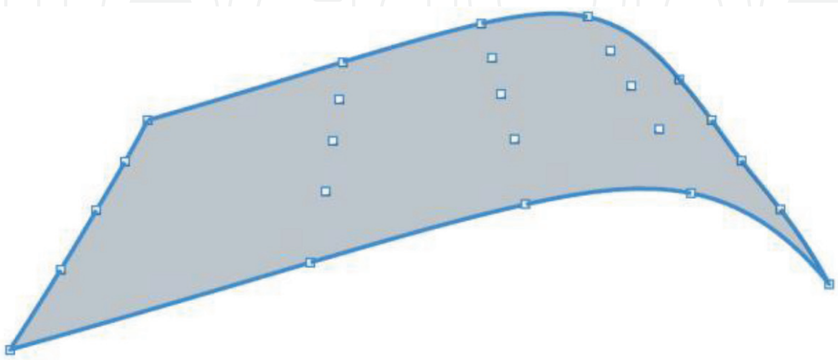

Figure 2. Accelerated surface.

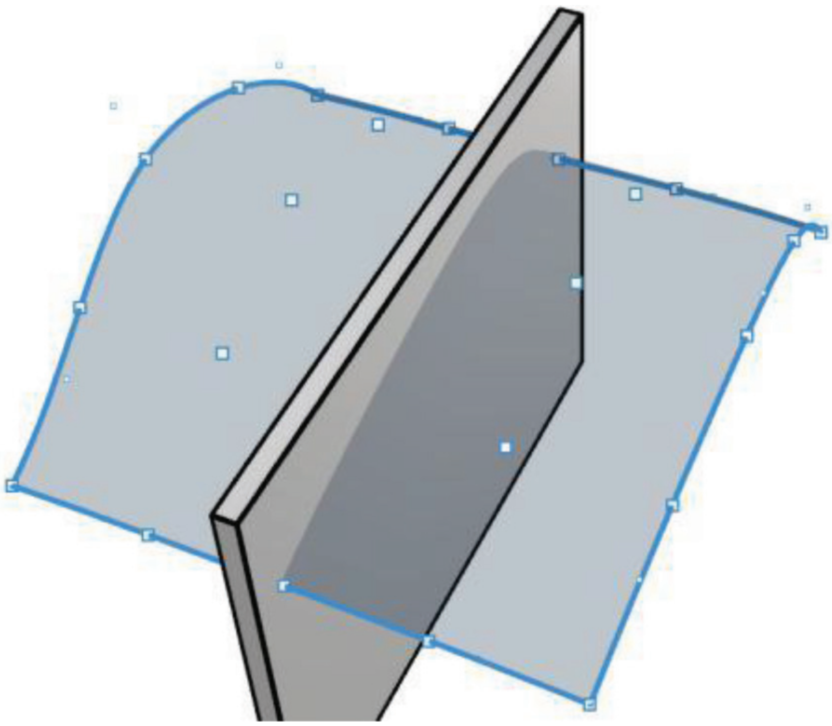

Figure 3. Symmetry.

2.2. Medical view of postural disorders and spinal deformity

2.2.1. Scoliosis

It is not easy to find appropriate, well-designed, and well-fitted garments for people with scoliosis. They are often faced with the problem of how to dress nicely and comfortably. Many different types of advice can be found in the source by Rudolf et al. [13] and, lately, these

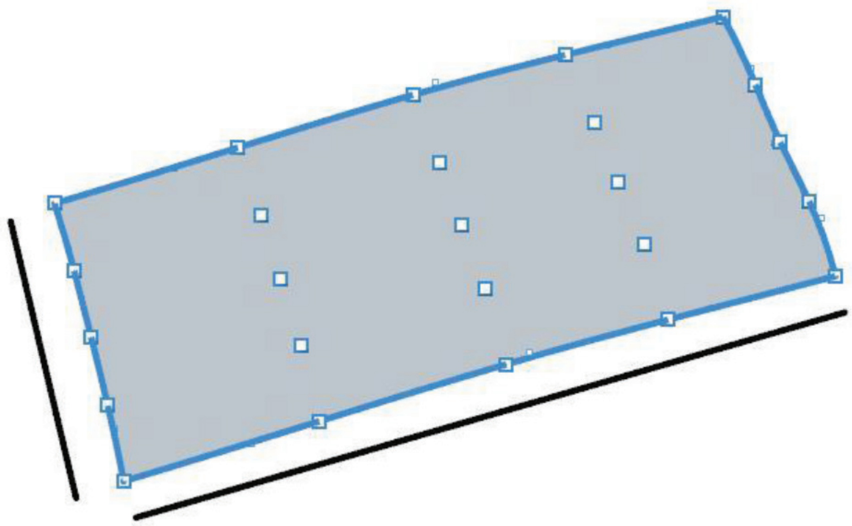

Figure 4. Proportionality.

can also be found on specialized webpages or blogs, as presented by Strauss [14] in "How to dress with scoliosis" or Munike Zanette Ávila [15] "Patternmaking for people with postural deviations."

Scoliosis can cause visible symptoms: uneven shoulders, uncentered, head, ribs at different heights, one shoulder blade that sticks out more than the other, uneven hips, one leg appearing shorter than the other, as well as the body leaning to one side. Because scoliosis causes this asymmetry in the body, imperfect and ill-fitting clothes can become a daily problem. The waist on pants or skirts may appear uneven, or shirts and dresses may not fit or hang on the body properly. Dressing in a way that makes the individual feel at their best and most secure with their scoliosis can become a challenge [15]. One of the easiest ways to mask scoliosis is to avoid tightly fitting clothing. Individuals with scoliosis tend to be small framed and long waisted, so their bones are generally very pronounced. Tight shirts can reveal the asymmetry more obviously. Not only can clothing like tight t-shirts and blouses emphasize the scoliotic deformity even more but also because there is an asymmetry on one side, the clothing might feel much tighter on one side than on the other making these types of clothing uncomfortable [14, 15].

2.2.2. *Kyphosis*

Kyphosis is the term used to describe an abnormal outwardly curved spine in the sagittal plane. The condition can contribute to a "hunchback" appearance, and may require exercise, braces, or spine surgery for treatment [16].

A certain degree of curvature is normal in the human spine. The gentle inward and outward curves of the neck, upper back, and lower back are necessary to maintain the body properly balanced and aligned over the pelvis. Kyphotic curved spines are the outward curves. Inward curved spines are called lordotic [16].

The term kyphosis is generally used to describe an excessive outward curve, or rounding, of the spine. Again, some kyphosis is normal—typically 20–50°; curves greater than 50° are considered abnormal. A spine with kyphosis can look normal, or it can develop a *"humpback"* appearance.

Mild kyphosis may cause few problems; however, severe kyphotic curvature can affect the lungs, nerves, and other tissues and organs, causing pain and other problems.

There are several types of kyphosis, and the condition can be found in children, adolescents, and adults.

Postural kyphosis, or postural round-back, is the most common form of kyphosis, and is often attributed to poor posture. Habitually, "slouching" can stretch spinal ligaments and contribute to abnormal vertebral formation. The condition usually appears during adolescence, and is more common in girls than in boys. Postural kyphosis is marked by a smooth, flexible curve that is not typically associated with pain, and usually does not lead to problems later in life [15, 16].

Scheuermann's kyphosis developed most commonly in teenage boys. It is characterized by a short, sharp curvature in the middle part of the upper spine, and may be associated with aching back pain. This type of kyphosis tends to be rigid on clinical examination. A mild degree of scoliosis is common in adolescents with Scheuermann's kyphosis.

Congenital kyphosis can be caused by a malformation of the spinal column during fetal development. Several vertebrae may be fused together or the bones may not form properly. This type of kyphosis may worsen as the child grows [16].

Self-image, or the way we feel about our bodies, can affect all aspects of our daily life. If we are wearing clothes that fit well and feel comfortable, this inevitably helps to boost our confidence. People with sustained spine deformity have problems with clothes that do not fit well in the back and front parts. They are tight across the back, too short in the back length (BL) and too long in the front length, open at the back of the neck and hemlines can become uneven, and so on [15].

3. Practical examples using CASP methodology

3.1. Curvature graphs

As we have already explained, the curvature graphs were not used directly, but were used just to show how they work. We will present some examples. Curvature graphs were used to determine non-symmetry on a real face scan as **Figure 5** shows. The highest peak on the curvature graph represents the nose, which is in the middle. The left and the right sides of the curvature graph will be symmetrically identical over this peak on a perfect symmetrical face, but it is not in this case. That way, we proof non-symmetry that is not obviously seen on a real face scan.

Figure 6 shows a series of increasing accelerated curves (a) with their curvature graphs (b) and a series of increasing decelerated curves (c) with their curvature graphs (d).

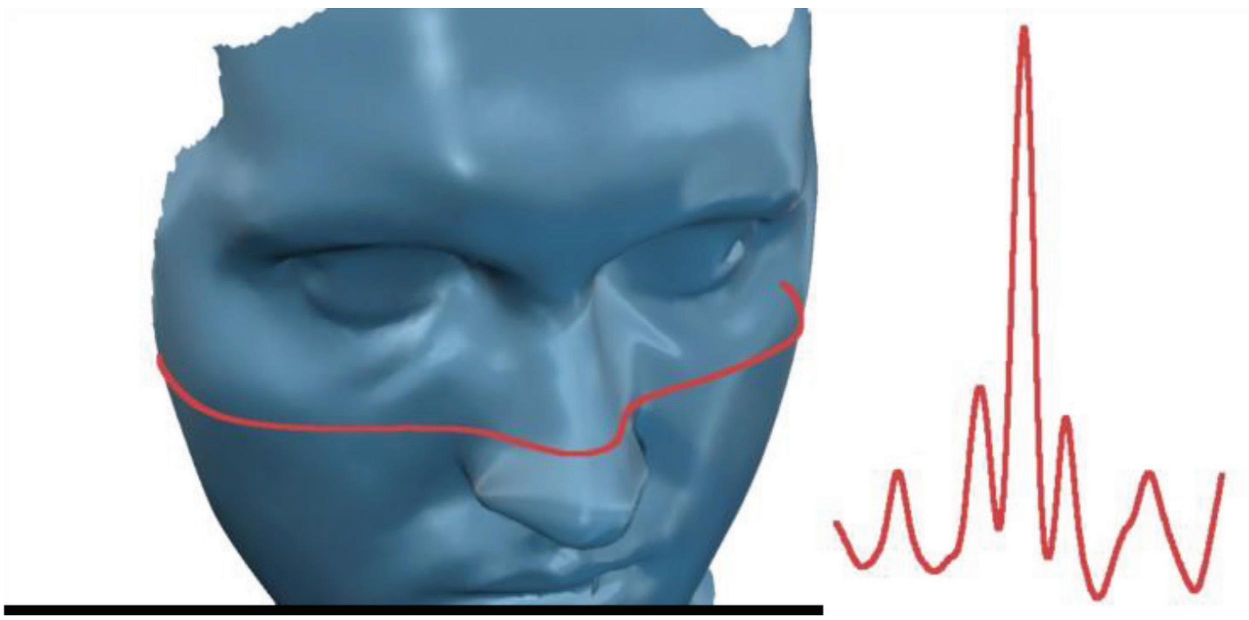

Figure 5. Symmetry on a cut-line of 3D-scanned human face. On the right side is the curvature graph [17].

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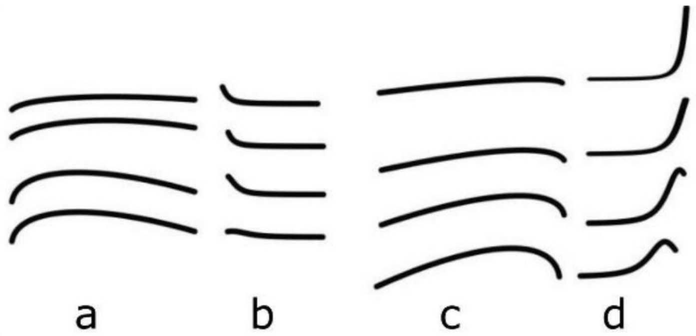

Figure 6. Increasing accelerated curves (a) and their curvature graphs (b). Increasing decelerated curves (c) and their curvature graphs (d) [18].

The last example of curvature graph use is the ergonomic fit of a thumb on the computer mouse as shown in **Figures 7** and **8**.

3.2. Virtual postural models

Virtual models were made using "Make Human" [19], an open-source program for human body creation. An open-source program "Blender" was used for posing [20], which means rotating or moving body parts virtually (in this case, the upper torso) to simulate not standard posture-scoliotic or kyphotic. 3D models that represent normal postures were used as reference and compared to models with postural deformity. The differences between them were determined with CASP values.

3.2.1. Scoliotic model

In our research on using the CASP methodology for virtual prototyping of garments for people with postural disorders and spinal deformities, we first created an artificial, symmetrical 3D female body without any deformity. Afterwards, this model was deformed in the left shoulder area. The deformity is typical for a girl or a woman with scoliosis, as shown in **Figure 9**.

Both body models presented in **Figure 9** were analyzed using the CASP method in the shoulder area as **Figure 10** shows.

The differences in CASP properties are primarily in the symmetry, which is expected, since we created the asymmetry artificially.

Figure 7. A user holds a computer mouse in the right hand [18].

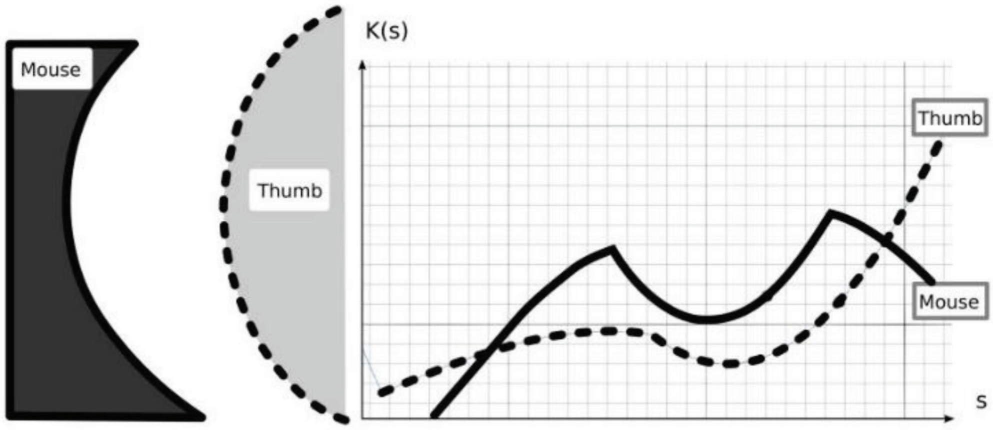

Figure 8. The shape of the thumb fits on the shape of the mouse and graph K(s) on the right side [18].

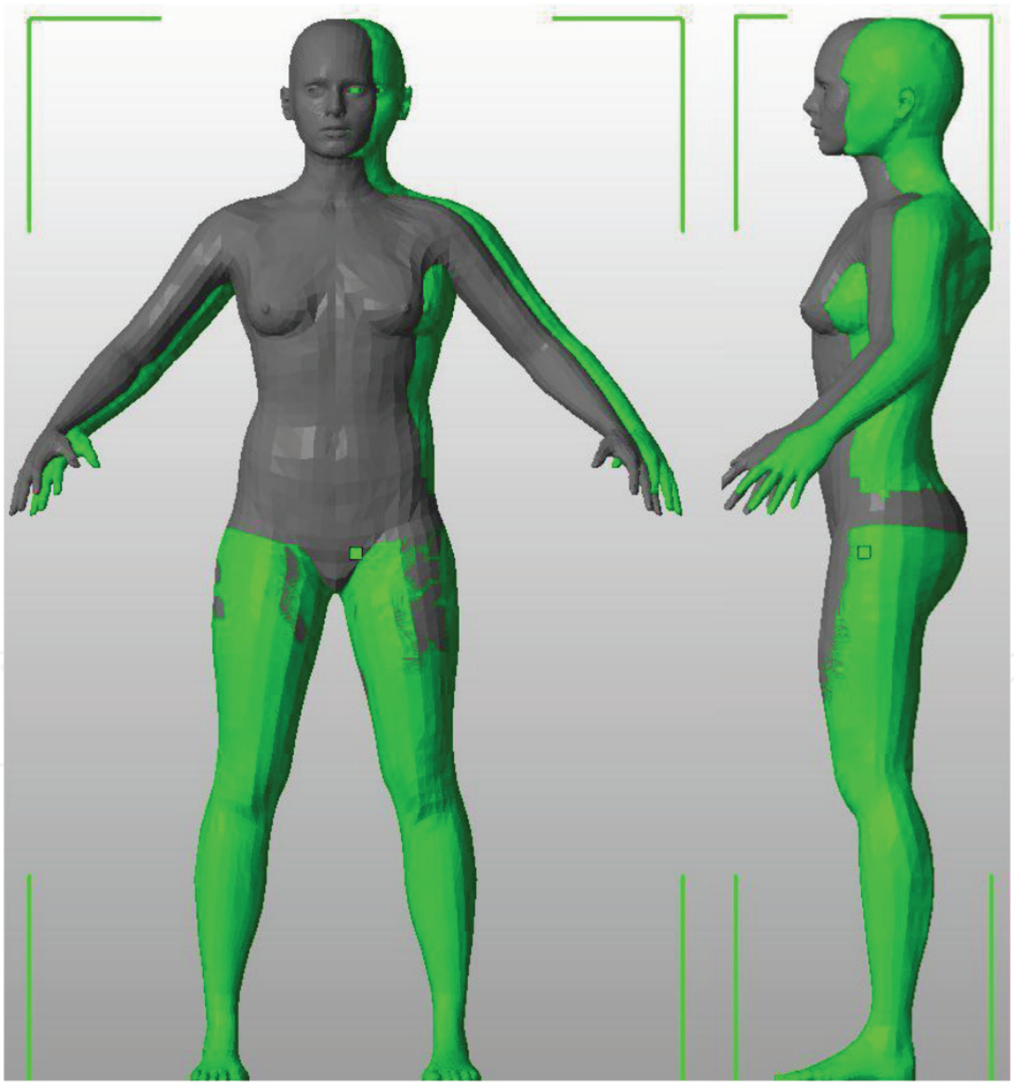

Figure 9. Normal (dark grey) and scoliotic synthetic female body (light grey) [21].

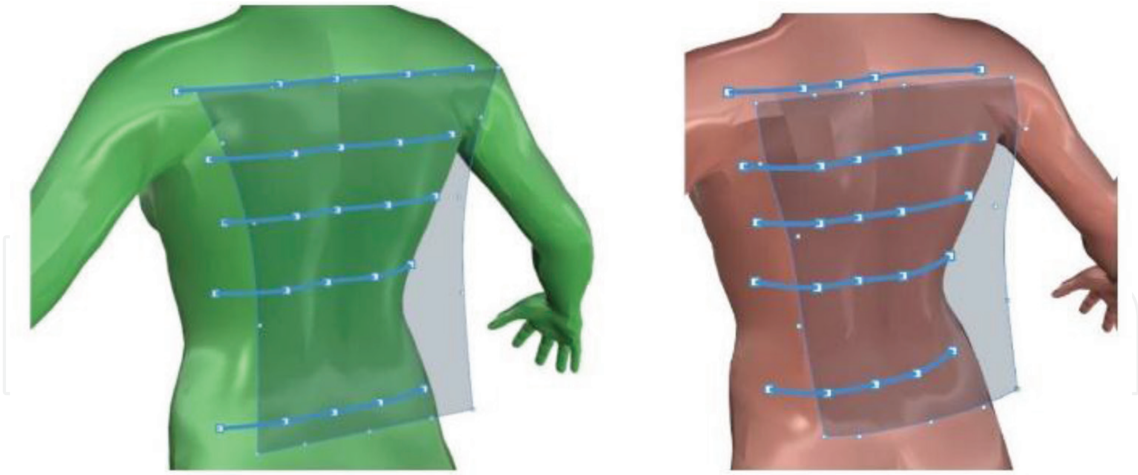

Figure 10. Cross-section parts on the back for a normal body (left) and a deformed body (right) [21].

The dress basic pattern design was constructed in the CAD computer program Optitex PDS (Pattern Design System) [22] according to normal (symmetric) synthetic female body dimensions by using the rules of the construction system by M. Müller and Sohn [23]. The construction system defines rules for construction of the garment pattern designs based on body dimensions and proportions. **Figure 11** presents fitting a dress on the normal and **Figure 12** on the scoliotic synthetic female body. The differences in the CASP values are also reflected in the dress's appearance. The deformed body is asymmetric. Because of the convex line, the

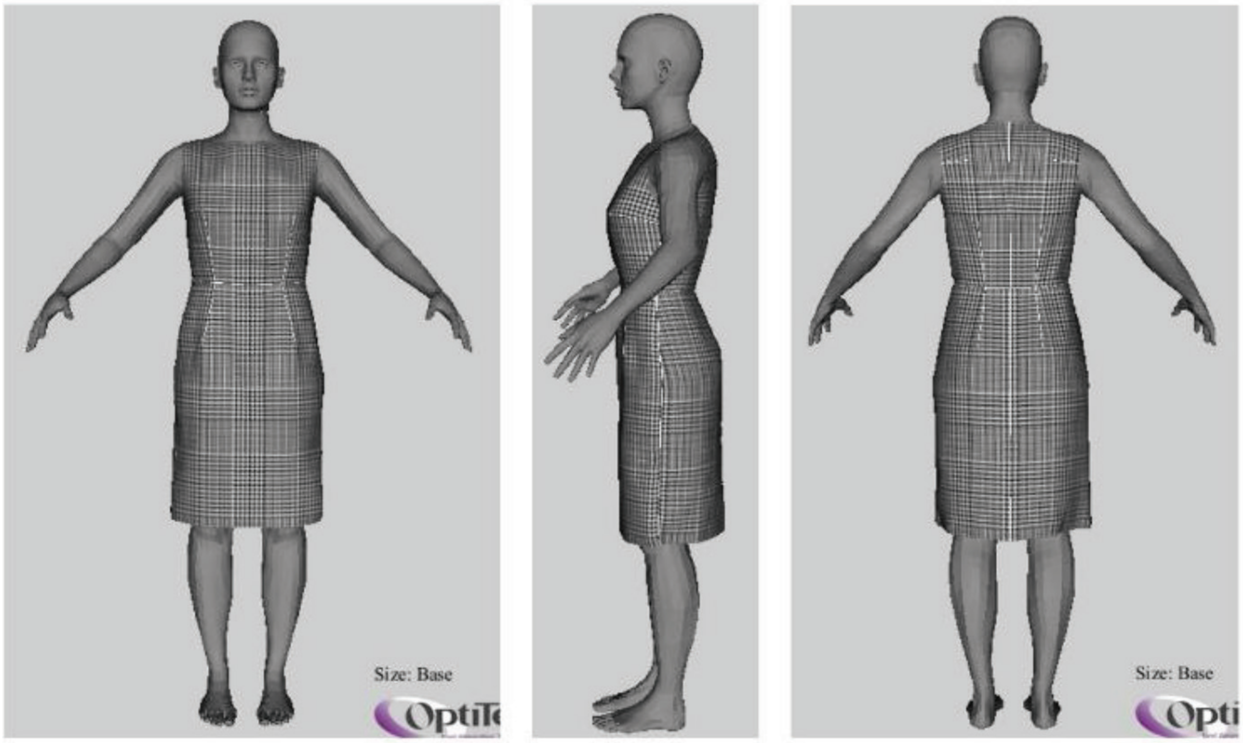

Figure 11. Basic dress pattern design on a normal synthetic body model [9].

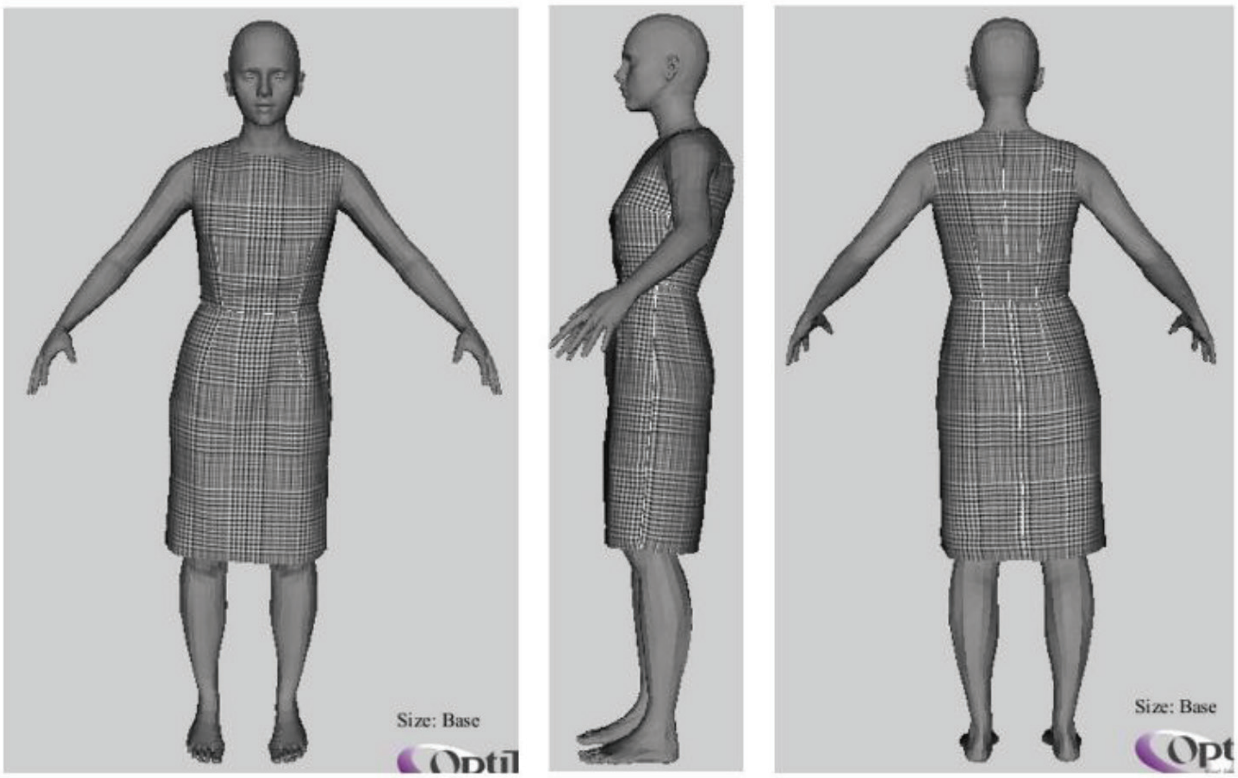

Figure 12. Basic dress pattern design on a synthetic scoliotic female body model [9].

straight seam in the middle of the back causes the appearance of the dress to increase the appearance of the asymmetry of the body. It is also observed in the movement of the parts and their asymmetry according to the body, and shortening of the dress on the right side of the body [9].

With reconstruction of the basic dress pattern design, we want to balance the appearance of the asymmetric body so that it looks as if the body is symmetrical. Contour corrections of the dress side seams, waist seams, and back middle seam in the blade area were performed, as well as contour corrections of the waist, breast, and blade darts, according to the fitting anomalies, as shown in **Figure 13**.

Adapted and not adapted basic dress pattern designs as virtual prototypes are presented in **Figure 14**. It is clearly visible that the reconstruction process of the basic dress pattern design improves the appearance and fit of the adapted dress to a deformed body. The seam in the middle of the back is aligned. Darts are symmetrical according to the center of the body. The seam line in the waist and dress edge are also aligned.

3.2.2. Kyphotic model

The body with a normal spine, and a kyphotic model with slightly curved, curved, and strongly curved spines, found in the case of kyphosis, were prepared in virtual space, as shown in **Figure 15**.

Figure 13. Comparison between basic dress pattern design (light grey) and adapted scoliotic dress pattern design (dark grey) [9].

All 3D body models were analyzed using the CASP methodology in the round-back area. The observation plane was projected on an imported body mesh model, as presented in **Figure 10**. Furthermore, calculations were executed by Grasshoppers' $n \times n$ procedure and values for CASP were obtained as a numerical result.

The virtual measurements of the back lengths were performed according to the Standard ISO 8559 [24] by using the Optitex PDS system [22]. The back length was measured precisely from the seventh cervical vertebra to the waist line. The waist girth in all 3D body models was 66.74 cm.

The results of the CASP analysis and measured back length are collected in **Table 1**.

In addition, differences were calculated between the normal spine and deformed spines for CASP parameters and back lengths, as well as quotients between the curvature differences

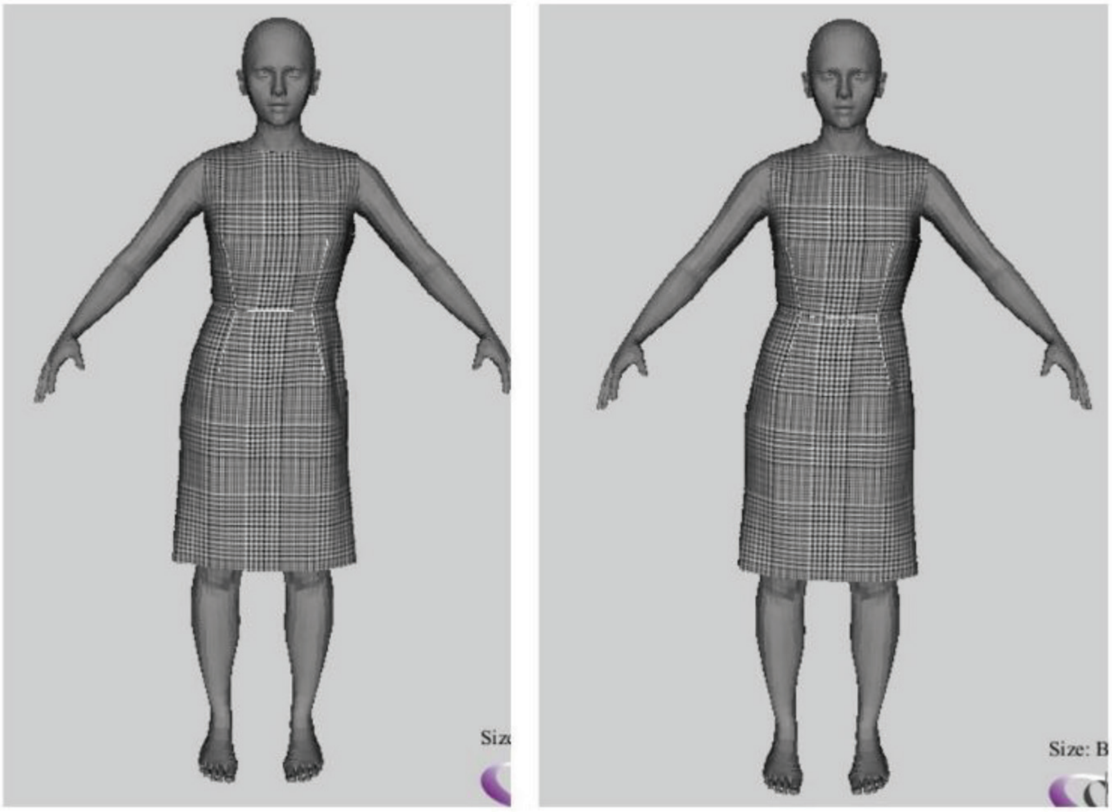

Figure 14. Not adapted and adapted (reconstructed) basic dress pattern design on a deformed body [9].

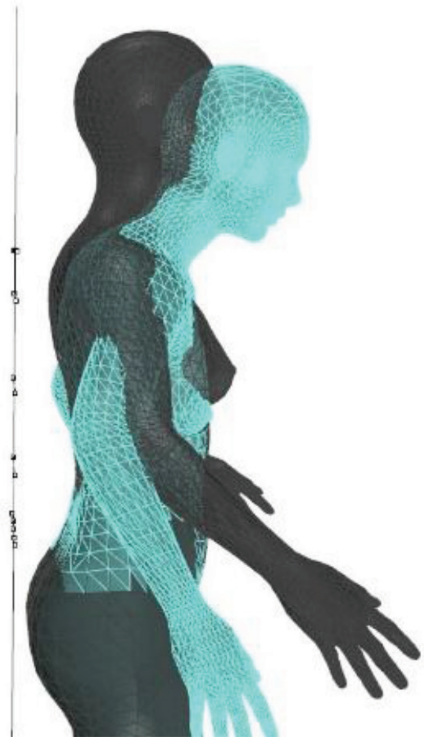

Figure 15. Normal (dark grey) and kyphotic (light grey) posture.

Spine	Normal	Slightly curved	Curved	Strongly curved
C	1.69	2.56	3.13	3.26
A	−3.73	−14.97	−55.79	−127.35
S	1.85	2.02	1/4	1.33
P	1.34	1.34	1.34	1.34
BL (cm)	33.19	34.95	36.14	36.31

Table 1. Values C (Curvature), A (Acceleration), S (Symmetry), P (Proportionality), and BL (back length) for normal and scoliotic models [25].

wand back lengths' differences, and between the acceleration differences and back lengths' differences, **Table 2**. The results show clearly that CASP values, especially Curvature—C and Acceleration—A, increase with an increase in the spine deformity. It seems that parameters Symmetry—S and Proportionality—P are independent regarding the spine deformity. This was also expected, because Symmetry—*S* measures differences between the left and right sides of the body. While the body was generated synthetically with a computer 3D program, the differences are negligible. The back length increases with an increase in the spine deformity.

A logarithmic graph chart of the **curvature difference** and **back length difference** was found when increasing the spine deformity. Logarithmic graphs have axes with logarithmic steps like 0.1/1/10/100/1000/10,000, and so on. The polynomial trend of the **acceleration difference** and the ratio DA/DBL was found with an increase in the spine deformity, **Figures 16** and **17**. Synthetically created body models were created with deformity of the upper spine with 5° steps. These equal steps caused chart trends of acceleration-dependent values presented in **Figure 15**.

The results show that the ratio DC/DBL is almost the same for all spine curvatures and equals 0.5, shown in **Table 2**. Therefore, it could be supposed that the back length difference is two times higher than the curvature difference. This means that it may be possible to include the CASP parameter for the curvature difference directly in the process of reconstruction of the garment pattern design to a specific body shape. The reconstruction of garment pattern

	Spine			
Parameter	**Normal**	**Slightly curved**	**Curved**	**Strongly curved**
DC	/	0.87	1.44	1.57
DA	/	11.24	52.06	123.62
DBL (cm)	/	1.76	2.95	3.12
DC/DBL (cm^{-1})	/	0.49	0.49	0.50
DA/DBL (cm^{-1})	/	6.39	17.65	39.62

Table 2. Values DC (curvature difference) and DA (acceleration difference). DBL (back length difference) and quotients DC/DBL and DA/DBL for scoliotic models [25].

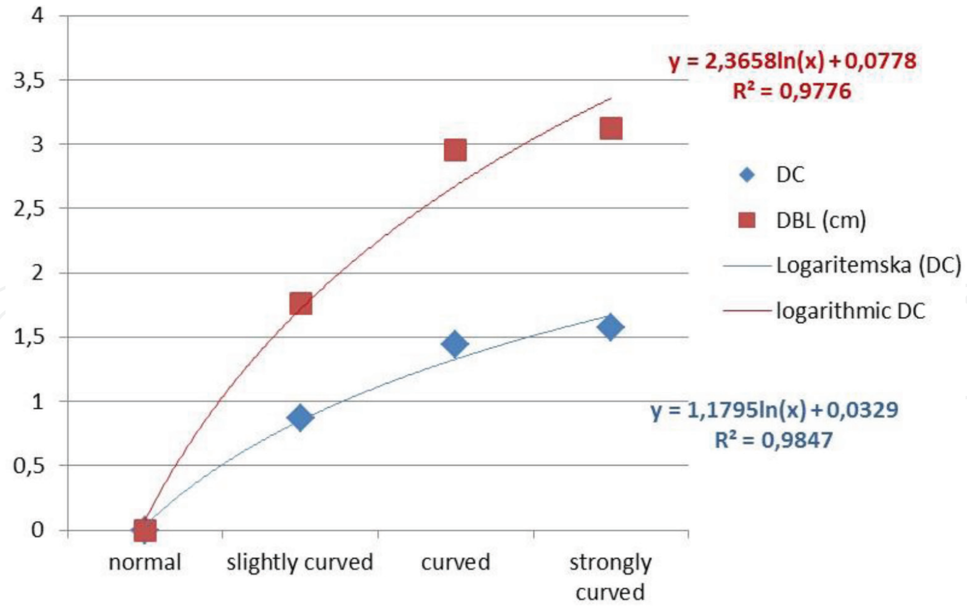

Figure 16. The curvature differences (DCs) and back length differences (DBLs) when increasing the spine deformity [25].

design is usually carried out by observation of the body shape and measuring of body dimensions, which is a lengthy process in terms of manufacturing and fitting clothing.

Based on the previous results, the constructed bodice basic pattern design was reconstructed according to the calculated value of the curvature difference for the slightly curved, curved, and strongly curved kyphosis spines. The virtual fittings of the bodice basic pattern design to a normal 3D body model and reconstructed bodice basic pattern

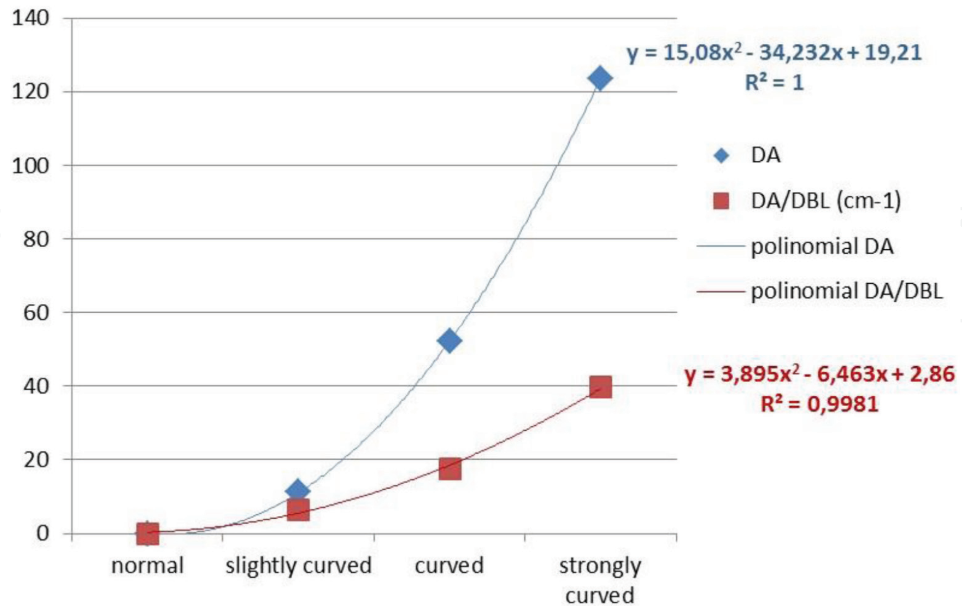

Figure 17. Acceleration difference (DA) and the ratio DA/DBL charts [25].

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designs were performed to the 3D kyphosis body models, **Figure 18**. During reconstruction, the front middles were shortened for the double value of CD and the back middles were extended for the double value of DC, while the back darts were extended and raised for the CD.

The results regarding the virtual fitting of the bodice basic pattern design to normal and kyphosis 3D body models show that, with an increase in the spine curvature, the bodice front length increases and the bodice back length decreases. Therefore, the waistline is not straight, and inappropriate fitting appeared.

The results regarding the virtual fitting of the reconstructed bodice pattern designs to a kyphosis 3D body model show the straightened bottom edge of all the simulated bodices. During reconstruction, the front middles were shortened by the double value of CD and the back middles were extended by the double value of DC, while the back darts were extended and raised by the CD. Based on these findings, it could be supposed that, with a reconstruction of the garment by using the measured and calculated CASP values and the curvature differences for curved spines, respectively, improved garments fitting would be achieved and, at the same time, wearing comfort in terms of garment pattern design.

It can be concluded that the CASP methodology could be adequate for defining the appropriate garment pattern design for persons with a curved spine. Therefore, it is definitely

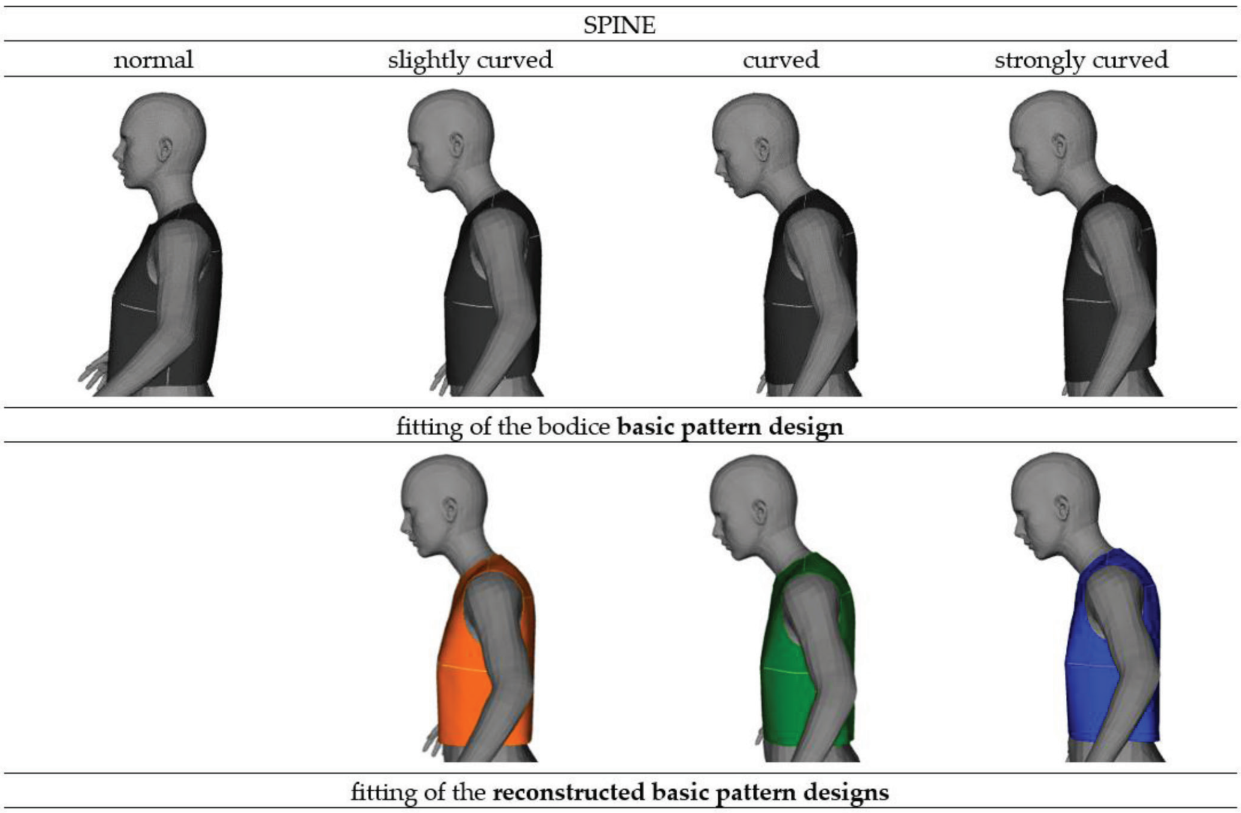

Figure 18. Fitting of the bodice basic pattern design (grey) and reconstructed bodice basic pattern designs [25].

necessary in the future to carry out additional research work on a larger number of diverse curvatures of the kyphosis spine with real persons, to confirm the findings of this research.

4. Results and discussion

The results of the CASP analysis and measured back length are collected in **Table 1**. It is evident that CASP values, especially Curvature—C and Acceleration—A, accrue with an increase in the spine deformity. It seems that parameters Symmetry—S and Proportionality—P are independent of spine deformity, which was expected, because Symmetry—S measures differences between the left and right sides of the body. While the body was generated synthetically with a 3D computer program, the differences are negligible. The proportionality—P depends on the observation frame, where the quotient is calculated between the length and width. In this case, the frame was the same for all models [25].

With an increase in the spine deformity, the back height increased, **Table 1**. The back length was measured with a computer program on a virtual model and was 33.19 cm for the normal spine, for the slightly curved spine 33.51 cm, and it increased for the strongly curved spine up to 36.31 cm. With an increase in the spine deformity, the bodice length on the back is too short and on the front too long. Therefore, the bodice in the front moves back to the neck, and thus compensates for the lack of the bodice length on the back. The result is an increase in the bodice tension in the area of neck and armholes when the deformity of the spine increases.

Virtual 3D models and virtual prototyping present an important approach to individual design and manufacturing. However, an individual treatment requires both sufficient time and suitably qualified people; therefore, not everybody can afford it. The future purpose is to enable virtual prototyping, including the design, construction, and visualization of adapted garments for people with postural disorders and spinal deformities to become more automated with 3D scanning, CASP methodology, and an established protocol.

The size of an object does not matter while CASP methodology performs normalization. For a scoliotic case, not all four parameters are observed, but just C and A while they show the curvature and acceleration of the back shape.

The ideal human body is symmetrical. The producers of ready-made garments cannot consider the deformity of a body caused by scoliosis, because they are specific and differ from case to case. Therefore, the only solution to improve the appearance and fit of the garment seems to be to adapt the garment pattern design to individual people.

5. Conclusions

In this chapter, advanced approaches such as virtual prototyping and multipurpose methodology CASP were used for designing dress patterns for people with postural disorders and spinal deformities such as scoliosis and kyphosis. Individuals can be analyzed with this methodology

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and the values obtained can be considered while the garment patterns are constructed. Dress fit is shown on virtual synthetic models. First, we took completely symmetrical designs for a normal body and prepared a dress that fitted well. Second, a digital scoliotic model was created and a third kyphotic model was designed with several increasing steps of spine deflection. The same dress used for a normal body did not fit well; therefore, an adapted dress pattern was developed. A satisfying correlation between the spine curvature and CASP values was obtained; therefore, it can be concluded that the CASP methodology could be adequate for defining the appropriate garment pattern designs for persons with a curved spine. In the future, we plan to carry out additional research work on a larger number of diverse body shapes of real people with postural disorders and spinal deformities to confirm the findings of this research.

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