CASP methodology applied in adapted garments for adults and teenagers with spine deformity

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ABSTRACT – REZUMAT

CASP methodology applied in adapted garments for adults and teenagers with spine deformity

The goal of the research presented in this article is to investigate the applicability of the CASP (Curvature, Acceleration, Symmetry, Proportionality) methodology for adapted garments' pattern design for real cases of adults and teenagers with spine deformity. The current research is the result of a collaborative work of Slovenian and Romanian research teams with common expertise and background. The results obtained by applying CASP methodology on theoretical case studies showed that this methodology could be adequate for assuring the appropriate garment pattern designs for real persons with kyphosis. In this research, the design stages of adapted garments for adults and teenagers with spine deformity were presented by using the CASP evaluation of the back and virtual prototyping of garments. The results of the study confirmed that reconstruction process of the basic shirt/blouse pattern design improved the appearance and fit of the product to the body with spine deformity. Also, this paper brings contributions to garment design technology by 3D scanning and virtual try-on, taking into account the body shapes of the users.

Keywords: *spine deformity, CASP methodology, 3D scanning, simulation, adapted garments*

Metodologia CASP aplicată articolelor de îmbrăcăminte adaptate pentru adulți și adolescenți cu deformări ale coloanei vertebrale

Scopul studiului prezentat în acest articol este de a cerceta aplicabilitatea metodologiei CASP (Curbură, Accelerare, Simetrie, Proporționalitate) pentru proiectarea tiparelor aferente articolelor de îmbrăcăminte adaptate pentru cazuri reale de adulți și adolescenți cu deformări ale coloanei vertebrale. Acest studiu este rezultatul unei colaborări a echipelor de cercetare din Slovenia și România, cu expertiză și preocupări comune. Rezultatele obținute prin aplicarea metodologiei CASP pe studii de caz teoretice au arătat că această metodologie ar putea fi adecvată pentru proietarea tiparelor de îmbrăcăminte corespunzătoare pentru persoanele care suferă de cifoză. În acest studiu, etapele de proiectare a articolelor de îmbrăcăminte adaptate pentru adulți și adolescenți cu deformări ale coloanei vertebrale au fost prezentate prin utilizarea evaluării CASP a spatelui și prototiparea virtuală a îmbrăcămintei. Rezultatele studiului au confirmat că procesul de reconstrucție al modelului de bază al cămășii/bluzei a îmbunătățit aspectul și ajustarea produsului pe corpul cu deformare a coloanei vertebrale. De asemenea, această lucrare aduce contribuții la tehnologia de proiectare a îmbrăcămintei prin scanare 3D și probare virtuală, ținând cont de forma corpului utilizatorilor.

Cuvinte-cheie: *deformări ale coloanei vertebrale, metodologia CASP, scanarea 3D, simulare, îmbrăcăminte adaptată*

INTRODUCTION

Garments must respond to various quality requirements expressed by users. In this context, the dimensional and shape correspondence between the user's body and the garment is essential in order to ensure the normal state of comfort while wearing the product and at the same time is a decisive factor in the purchasing of the product by the user.

On the market, it is difficult to find clothes for people with non-standard body shapes. Furthermore, there are people with different spine deformities, who also need well-designed and well-fitted garments.

Spinal deformities may be the result of many conditions, such as congenital malformation of the spinal column, disorders of the neuromuscular system or trauma. They may be progressive in which case their severity increases with age, leading to restrictions of pulmonary growth, nerve function and heart pumping capacity [1].

Deformations of the spine in early childhood and the nat puberty can cause problems in the mature period, because in the early stages of development irregular spine curvatures can occur: kyphosis (excessive curvature of a larger or smaller part oft he spine – rounding of the upper back, also called round back, hunchback), lordosis (exaggerated forward curvature of the spine in the lumbar region-belly is bulging and protruding forward) or scoliosis(on one and/or the other side S-shaped curved part or the whole spine). The normal spine, when viewed from behind, appears straight throughout its entire length, whilst from the side, when observing the thoracic and lumbar part of the spine, there are two visible curvatures: a gentle rounding of the upper back from the shoulders to the bottom of the ribcage known as thoracic kyphosis

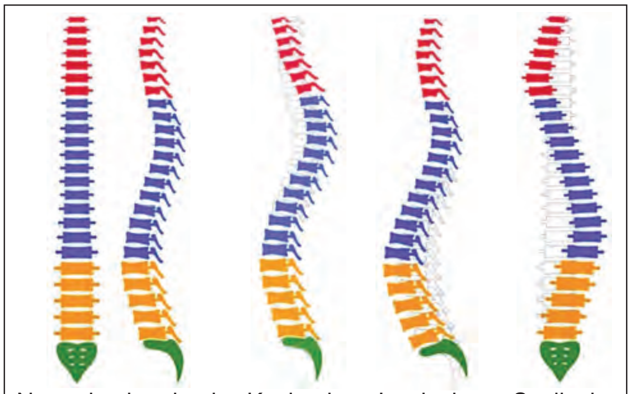


Fig. 1. Spinal deformity types [1]

and an opposite curve in the lower back known as lumbar lordosis. These two opposite curvatures of the spine are necessary in the normal spine to balance the trunk and head over the pelvis. A normal thoracic spine extends from the 1st to the 12th vertebra and should have a slight kyphosis ranging from 20° to 45° (figure 1). When the "roundness" of the upper spine increases past 45° it is called "hyperkyphosis" [2].

Spine deformity has both physical and emotional implications. Especially at the age of adolescence, physical aspect is an important one, affecting even the integration of young persons into society.

Adolescence is the period of biological, psychological and social transition from puberty to adulthood, when people become more concerned about their own image and their position in relation to others. A great part of adolescent clothing styles are very close-fitted clothing products and therefore, should aesthetically fit humans' bodies. Appropriate garments that mitigate deficiencies and assures functionality, comfort and a general appearance contributes to mental health of the users. Thus, it is necessary to identify the conformational and posture changes and to study the ways to mask the defects, but to ensure the psycho-sensorial comfort. At the same time, care must be taken to ensure static and dynamic comfort, because some physical changes also involve changing the amplitude or direction of movement of the limbs or the body in general [3].

Adults and teenagers with sustained spine deformation 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 and too long in the front length, open at the back of the neck, hemlines can become uneven etc. [4].

Recent research works highlighted the complexity of 3D human body scan data modelling [5–9] and developed an interactive virtual try-on based three-dimensional garment block design for disabled people, especially of scoliosis type [10–12].

The results obtain by applying CASP methodology on theoretical case studies showed, that this methodology could be adequate for assuring the appropriate garment pattern design for real persons with curved kyphosis [13–15].

The main aim of this research is to investigate the applicability of the CASP (Curvature, Acceleration, Symmetry, Proportionality) methodology for adapted garments' pattern design for real cases of adults and teenagers with spine deformity. The current research is the result of collaborative work of Slovenian and Romanian research teams with common expertise and background.

EXPERIMENTAL WORK

Scanning of studied teenagers using VITUS SMART – HUMAN SOLUTIONS

The anthropometric survey developed by INCDTP in Romania among boys and girls aged 6–19 years [16], was conducted by using the mobile scanning system Vitus Smart with software Anthroscan of Human Solutions Group (figure 2). The equipment used to measure the children and teenagers was the three-dimensional scanner (3D), constructed in accordance with EN ISO 20685:2005 "3-D scanning methodologies for internationally compatible anthropometric databases". Data acquisition on the human body shape and size was made in accordance with ISO 7250 "Basic human body measurements for technological design" and ISO 8559 "Garment construction and anthropometric surveys – Body dimensions". Therefore, 2900 children were scanned, of which were retained for statistical processing 1375 boys and 1476 girls.

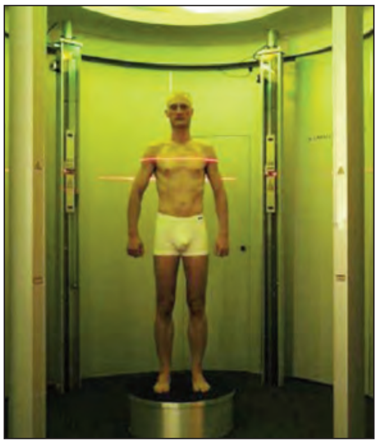


Fig. 2. Scanning system Vitus Smart

During the anthropometric survey, the research team met children with bodies that deviated from normality, both in terms of size as circumferences, lengths and widths and as proportions and body postures. The most common changes in conformation and posture were due to deficiencies in the back, legs, uneven disposition of body fat etc.

From these cases, there have been selected two subjects with kyphosis: female teenager aged 18 years (TF1) and a male teenager aged 18 years (TM1) (figure 3).

These children and teenagers represent a category of wearers for that garments designed based on anthropometric standards are not conformable, requiring the design of customized patterns that take into account the conformational changes of posture and special needs.

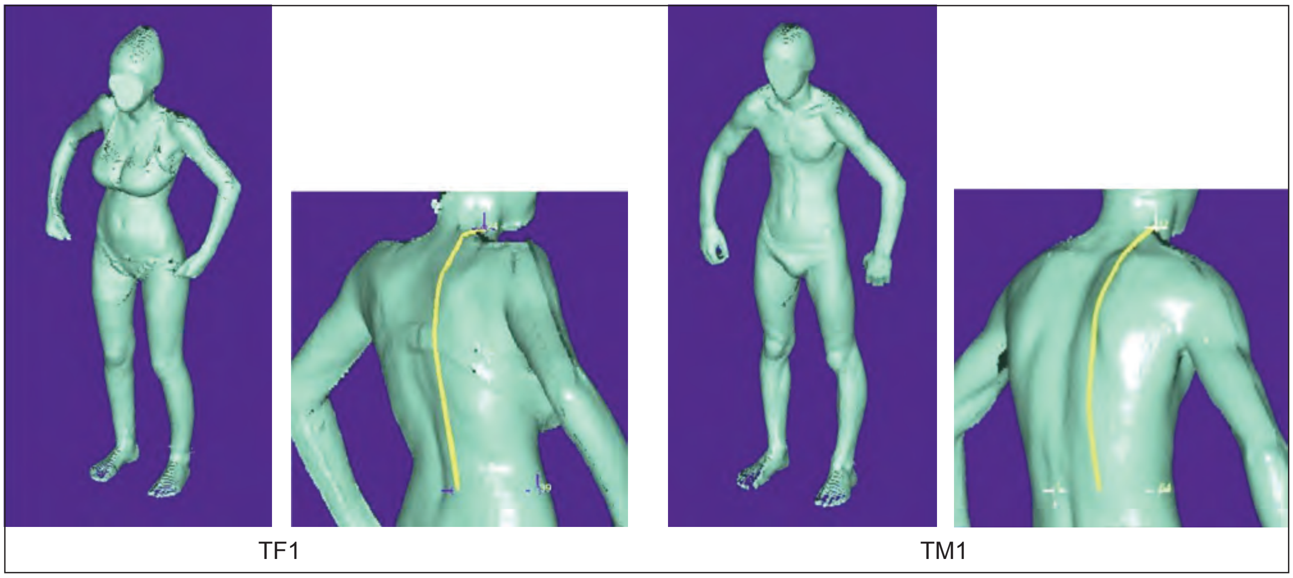


Fig. 3. Scanned bodies of the studied teenagers [16]

Scanning of studied adults using the HP 3D SCANER PRO

In this research, scanning of two Slovenian adults with kyphosis, female aged 40 years (TF2) and male aged 50 years (TM2) was performed using the HP 3D SCANER PRO optical scanning system for obtaining a standing 3D body model intended for virtual prototyping of the adapted garments [17].

3D scanner HP S3 (HP 3D SLS S3) is a structured light scanner (SLS). It is a general-purpose scanner intended for different engineering applications. According to the size of the product, which will be scanned several calibration panels are offered 30 mm, 60 mm, 120 mm, 240 mm and 480 mm. With the last one, the scanner's maximum measuring size is about 700 mm, which is enough to scan the human upper body part, which was also in the focus in this research. That human body can be scanned with this general purpose scanner, a rotating platform was developed. During scanning, the scanner was static, whilst persons were rotated for every 45° to scan the whole body around 360°. Tested persons had slightly upraised arms, breathing normally and wearing a tight undershirt during the scanning process. Scanning with upraised arms was carried out for the purpose of the adapted garments' virtual prototyping [18]. Using the HP 3D SCANER PRO software separate scans were polygonised into one independent mesh (figure 4, *a*). Usually cleaning and manual alignment was required. Also, some smoothing and holes closing were done. This mesh can be finally exported. Further processing was done by using programs Blender and Gom Inspect in order to prepare the mesh with smoothing and manually adjusting and moving mesh under arms and other possible irregularities (figure 4, *b*).

The scanned bodies' dimensions and garments pattern design

The virtual measurements of the scanned teenagers' bodies dimensions (TF1, TM1) were performed by using the Anthroscan software.

The female teenager (TF1) selected in this study represents a case of atypical development in the bust area, so the posture changes by bending the body to the anterior part. The garments with shoulder support for girls with these changes compared to those corresponding to their age group and height are uncomfortable, with the feeling of discomfort in the area of

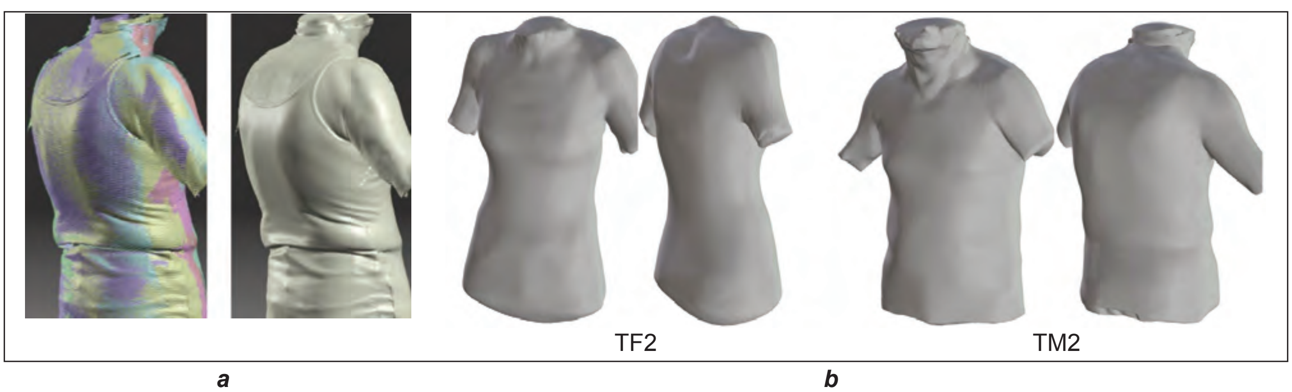


Fig. 4. Polygonised scans into: *a* – one independent mesh; *b* – scanned bodies of the studied adults

the bust and the appearance of unsightly folds in the area of the axle.

For the male teenager (TM1) selected in this study, the first step was to identify the area or areas with atypical modifications of conformation and posture. This is a case of changing of the posture through spine deformity, as can be seen in figure 3, the cervical area having a deflection to the anterior part and the torso shows a larger rounding than normal.

The anthropometric data needed to design the adapted blouse for the female teenager and the adapted shirt for the male teenager are collected in tables 1 and 2. The real anthropometric dimensions are compared with calculated proportional body dimensions (armscye depth, back length, hips depth, breast/chest width, armscye width, back width, front length, neck width). Among these proportional dimensions, the breast/chest width, armscye width, back width and neck width were only calculated. The determination of the anthropometric data was performed according to the ISO 8559 [19], whilst the proportional equations was used according to the construction system M. Müller&Sohn [20–21]. The adult tested persons, the female (TF2) and male (TM2) represent a case of posture resembling kyphosis. The determination of the anthropometric data and used proportional equations for comparison of the virtually measured bodies dimension with calculated proportional dimensions were carried out according to the same standards as for the teenagers. In addition, dimensions of adults were measured virtually using the Optitex PDS 3D software tool. The anthropometric data needed to design the adapted blouse and shirt for adults are collected in tables 3 and 4.

For garments pattern design we have used the software program Optitex PDS and its module 3D for virtual prototyping of garments and evaluation of garment fitting to 3D bodies models. The functionalities work well for patterns, intended for garments for people without body deformations. In cases, related to the pattern design of adapted garments for people with body deformations, such as those seen in bodies with kyphosis, we need to apply a scanned 3D body model of the individual person instead of a standard 3D body model and perform additional analyses. Namely, the commercial PDS packages do not offer functionalities for supporting special requirements for adoption of 3D body models to different postures. Therefore, scanned 3D bodies models of teenagers and adults were imported into the Optitex PDS 3D. The basic pattern designs of blouses and shirts without sleeves and waist darts were constructed according to measured bodies dimensions and needed calculated proportional dimensions

Table 1

SYNTHESIZING THE DATA FOR THE STUDIED PERSON **TF1**

Anthropometric dimensions	Abbr.	Measured body dimensions (cm)	Calc. of prop. body dimensions	Calculated body dimen. (cm)
Body height	BH	163.0		
Breast/Chest girth	BG	91.0		
Waist girth	WG	68.5		
Hips girth	HG	87.0		
Armscye depth	AD	23.0 (+4.0)	1/10 BG + 10.5 cm	19.0
Back length	BL	40.0 (0.0) *over the blades* *43.0 (+3.0)*	1/4 BH – 1.0 cm	40.0
Hips depth	HD	59.0 (–2.0)	3/8 BH	61.0
Breast/Chest width	BW		1/4 BG – 4.0 cm	17.2
Armscye width	AW		1/8 BG – 1.5 cm	9.2
Back width	BW		1/8 BG + 5.5 cm	16.1
Front length	FL	43.0 (–1.0)	BL + 4.0 cm	44.0
Neck width	NW		1/20 BG + 2.0 cm	6.5
Shoulders length	SL	13.0		

Table 2

SYNTHESIZING THE DATA FOR THE STUDIED PERSON **TM1**

Anthropometric dimensions	Abbr.	Measured body dimensions (cm)	Calc. of prop. body dimensions	Calculated body dimen. (cm)
Body height	BH	177.0		
Neck girth	NG	42.0		
Breast/**Chest** girth	CG	85.0		
Waist girth	WG	74.0		
Hips girth	HG	90.0		
Armscye depth	AD	24.0 (+ 3.5)	1/10 CG + 12.0 cm	20.5
Back length	BL	44.0 (–4.0) *over the blades* *48.0 (0.0)*	1/4 BH + 2.0 cm	48.0
Breast/**Chest** width	CW		2/10 CG – 1.0 cm	16.0
Armscye width	AW		1/10 CG + 2.0 cm	10.5
Back width	BW		2/10 CG – 1.0 cm	16.0
Chest length	CL	22.0 (+2.5)	AD – 1.0 cm	19.5
Neck width	NW		1/6 NG	7.0
Shoulders length	SL	15.0		

(BW/CW, AW, BW, NW) by using rules of the construction system M. Müller & Sohn [20, 21]. Reasons for this are greater differences between the calculated and measured body dimensions (AD, BL, HD, FL, CL), which can be seen in tables 1–4. These differences were expected, especially for the back length, armscye depth, front of chest length. All garments were constructed with 3.0 cm ease allowances in the breast/chest girth, waist girth and hips girth. Virtual simulations of garments were carried out with the aim to analyse garments fitting to 3D bodies models. The waist darts were released on females' blouses in order to avoid the tensions that would result from them (each stitch causes tension) and to divert attention when assessing the fit of clothing in the upper spine with the Tension tool of the Optitex PDS 3D program.

Table 3

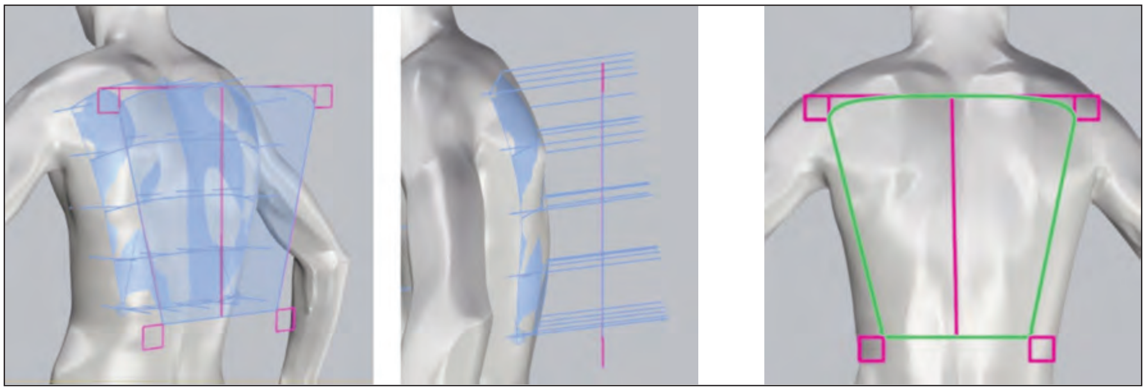
SYNTHESIZING THE DATA FOR THE STUDIED PERSON **TF2**				
Anthropometric dimensions	**Abbr.**	**Measured body dimensions (cm)**	**Calc. of prop. body dimensions**	**Calculated body dimen. (cm)**
Body height	BH	168.0		
Breast/Chest girth	BG	76.0		
Waist girth	WG	62.0		
Hips girth	HG	82.0		
Armscye depth	AD	22.0 (+1.5)	1/10 BG + 10.5 cm	18.5
Back length	BL	36.5 (–4.5)	1/4 BH – 1.0 cm	41.0
Hips depth	HD	54.0 (-9.0)	3/8 BH	63.0
Breast/Chest width	BW		1/4 BG – 4.0 cm	15.0
Armscye width	AW		1/8 BG – 1.5 cm	8.0
Back width	BW		1/8 BG + 5.5 cm	15.0
Front length	FL	38.0 (–7.0)	BL + 4.0 cm	45.0
Neck width	NW		1/20 BG + 2.0 cm	6.0
Shoulders length	SL	8.5		

Table 4

SYNTHESIZING THE DATA FOR THE STUDIED PERSON **TM2**				
Anthropometric dimensions	**Abbr.**	**Measured body dimensions (cm)**	**Calc. of prop. body dimensions**	**Calculated body dimen. (cm)**
Body height	BH	172.0		
Neck girth	NG	46.0		
Breast/**Chest** girth	CG	101.0		
Waist girth	WG	93.5		
Hips girth	HG	100.0		
Armscye depth	AD	32.0 (+10.0)	1/10 CG + 12.0 cm	22.0
Back length	BL	49.0 (+4.0)	1/4 BH + 2.0 cm	45.0
Breast/**Chest** width	CW		2/10 CG – 1.0 cm	19.0
Armscye width	AW		1/10 CG + 2.0 cm	12.5
Back width	BW		2/10 CG – 1.0 cm	19.0
Chest length	CL	25.0 (+4.0)	AD – 1.0 cm	21.0
Neck width	NW		1/6 NG	8.0
Shoulders length	SL	12.0		

CASP methodology to study teenagers and adults' upper back

The CASP (Curvature, Acceleration, Symmetry, Proportionality) methodology was originally developed as a method for classification of perceptual surfaces and for analysing digital geometry [22]. Methodology of surface evaluation was developed to establish the meta-language in design communication, which was perceived as necessary part of styling. The first step was the analysis of existing geometry and the second a synthesis of newly created geometry considering the desired property. Four properties, which characterize surfaces similar as colours in colour space [23], where each colour is represented as a mix of values L*, a* and b*. The surface's geometrical space consists of these four properties: Curvature – C, Acceleration – A, Symmetry – S and Proportionality – P. In addition, it was found out that CASP methodology is suitable for the purpose of analysis of the deformed areas of a human's body and adapted garment's pattern design for people with scoliosis and kyphosis [13–15]. In this research, the CASP methodology was applied on real bodies with spine deformity, mainly to evaluate the degree of curvature and symmetry of the upper spine or the roundback. All the studied subject, adults and teenagers, presented in figures 3 and 4, were analyzed in the roundback area by using the CASP methodology (figure 5). The observation plane was projected on an imported body mesh model. The area of the observation plane was defined according to the acromion points and waistline, and shoulder width and waist width, respectively. The observed area was corrected with offset of 3 cm to the inside to avoid that the procedure vector misses the scanned mesh (figure 5). Further calculations were executed using the Grasshopper's



a *b*

Fig. 5. Using the CASP methodology for:
a – the roundback area analysis; *b* – corrected area of 3 cm to the inside

nxn procedure. Values for CASP were obtained as numerical result. In addition, analysis of the CASP values and 3D bodies models' postures were carried out in order to find out if there is any connection between the CASP values and spine deformities that can be implemented into the garments basic pattern designs' adaptions with the aim to improve the garments' fitting to the bodies and to increase the wearing comfort. Namely, to the extent that CASP values allow us to more easily adapt a garment to a person with spinal deformity, such an analysis is much simpler than the method of observing the body, since the clients for whom we make custom-made garments usually do not undress to their underwear (a tight t-shirt).

RESULTS AND DISCUSSION

Analysis of garments' fitting to 3D bodies models

The virtual fitting of the basic blouses and shirts pattern designs designed for standard bodies' postures without deformation of the spines are shown in figures 6 and 7. For both female tested persons (TF1, TF2) a good fitting of the blouses to bodies on the front parts can be seen, while the fit is worse on the back (figure 6, *a*). This is especially pronounced for the test person TF1 with strong breasts, which may result from a greater curvature of the spine in the waist region (figure 6, *b*). The reason for worse fitting of the blouse on the back is waist darts, which were released during construction. When observing the tension in the garments, greater tension in breasts' girths region is evident, especially for the female teenager (TF1) with strong breasts (figure 6, *c*). Therefore, it can be assumed that the weight of the breasts can be cause of a curvature of the shoulder blades' upper part, resulting in a tension of the back armhole and shoulder seam. The latter indicates that for persons with strong breasts a greater ease allowance should be added for greater wearing comfort (we have added 3 cm), especially on the chest width and the armscye width. When comparing a female teenager and an adult, it can be seen that the adult TF2 has a curved entire upper part of the spine, which is characteristic for kyphosis, reflecting the transverse lines of tension (green) on the upper and lower shoulder blades parts. This is probably also the cause of the higher average tension of the garment in relation to the body, which is for an adult TF2 of 11.54 fg/cm and a teenager TF1 of 7.42 fg/cm, measured with a.

For both male tested persons (TM1, TM2) a good fitting of the shirt to bodies on the front parts can be seen, while the fit is worse on the back for the teenager TM1 in the neck area, where wrinkling of the neckline arose (figure 7, *a*). During the scanning the arms position caused tightening of the shoulder blades, which resulted in natural wrinkling of the shirt neckline (figure 7, *b*). Therefore, any shirt reconstruction was not needed in this area. Evident tension in the area of shoulder blades, because of a typical spine kyphosis can be seen when observing the shirts' tension in relation to the body on the back parts of both tested persons (figure 7, *c*). For both tested persons TM1 and TM2, we assume that the seam of the shoulder strap is in the wrong position, which contributes to the tension. In addition, the volume of the shirt in the shoulder blades area needs to be increased to reduce the tension of that area on the body. An average tension of the shirt in relation to the body is for an adult TM2 8.65 fg/cm and for a teenager TM1 5.77 fg/cm, also measured by using a Tension tool of the program Optitex PDS 3D.

CASP and scanned persons' postures analysis

The results of the CASP evaluation of the posterior body area (figure 5) are collected in table 5. In the previous research regarding the CASP evaluation of the synthetic 3D body model with differently curved kyphotic spines it was found that, especially Curvature – C and Acceleration – A increase with an increase in the spine deformation and parameter C was used in the garment's reconstruction procedure to enhance the wearing comfort [14]. In this research, the real 3D scanned bodies were evaluated [24].

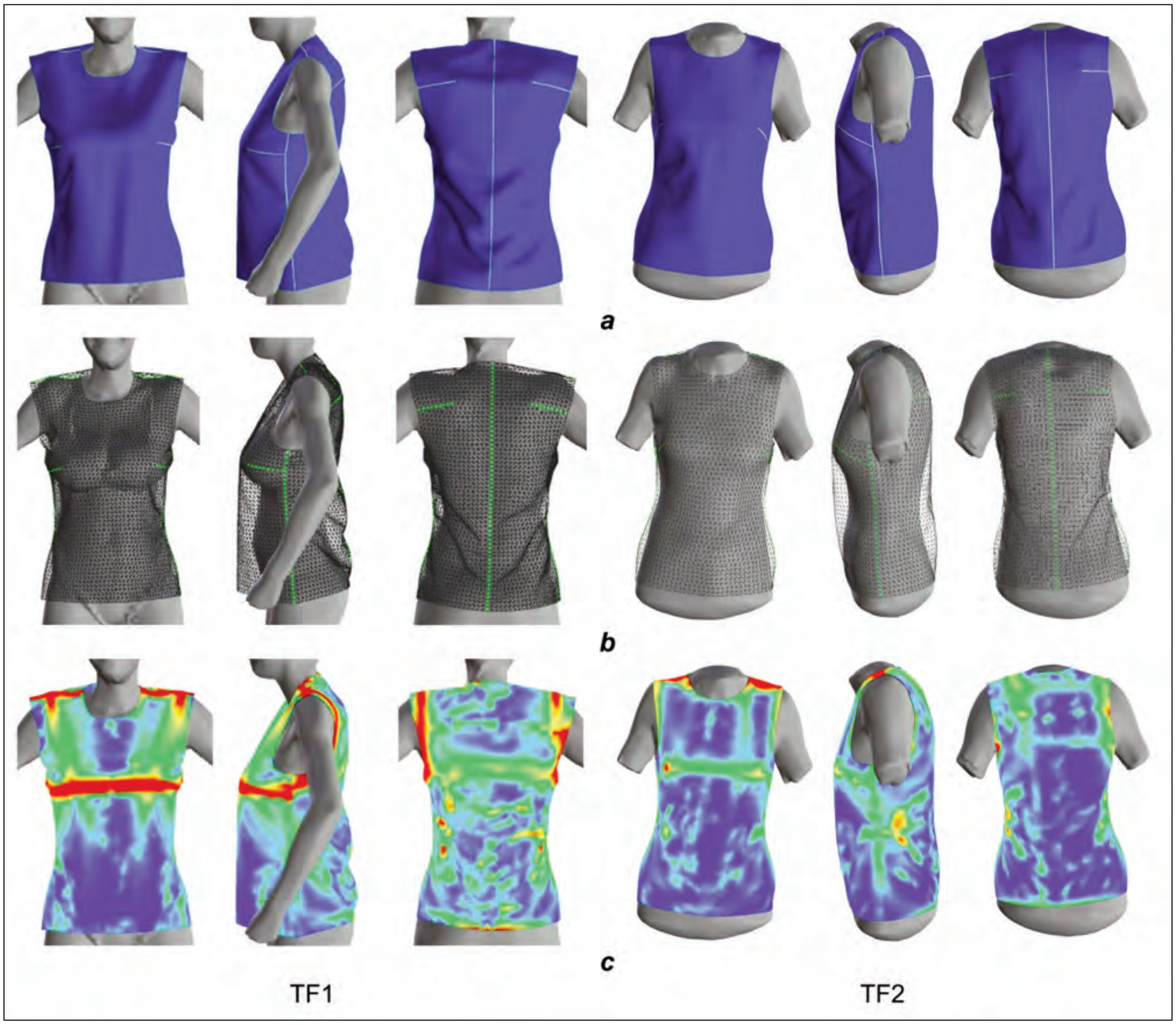


Fig. 6. Virtual fitting of the sleeveless basic blouses pattern designs to TF1 and TF2

Curvature is positive for surfaces where normal vectors dissipate and negative where vectors congregate. For our observed regions, the curvature is expected to be positive. Acceleration is a surface property, which describes if the observed surface has more curviness in the first or in the last half. Symmetry is an obvious property and equals to zero at perfect symmetry. For higher numbers the surface is less symmetrical. Proportionality indicates the ratio between height and width of the observed area. Properties A and P are not mandatory for this research.

The results of the parameter C show the highest curvature of the spine for both male tested persons TM2 (8.13) and TM1 (6.87) and lower for the female tested persons TF2 (6.54) and TF1 (6.25) (table 5). Both adults, female and male, have higher C parameter values than teenage female and male, meaning a potentially more pronounced kyphotic spine. The shape and curvature of the spine shown in figure 8 indicate that the adult test subjects TM2 (8.13) and TF2 (6.54) have greater kyphosis deformity than teens TM1 (6.87) and TF1 (6.25). Therefore, we believe that the value of parameter C can be reliably included in the process of reconstruction of the garment as predicted in the study [14]. We can also see a smaller scoliosis for both female tested subjects TF1 and TF2 and possibly lordosis of the female teenager TF1 (figure 8). More visible scoliosis shows the teenager female person TF1, which also indicates the highest parameter S of 56.28 (table 5, figure 8). In addition, pronounced blades are the result of arms postures while scanning the teens. The female teenager probably does not have kyphosis but curves the shoulder area because of strong breasts. Therefore, we had focused in continuation on clothes customization to increased wearing comfort for the TF1 test person in the breasts area and for other tested persons in kyphotic area. Both adults have similar asymmetry and parameter S at about 20, respectively. Asymmetry could be also caused by posture during the scanning process. It can be concluded that the higher value of

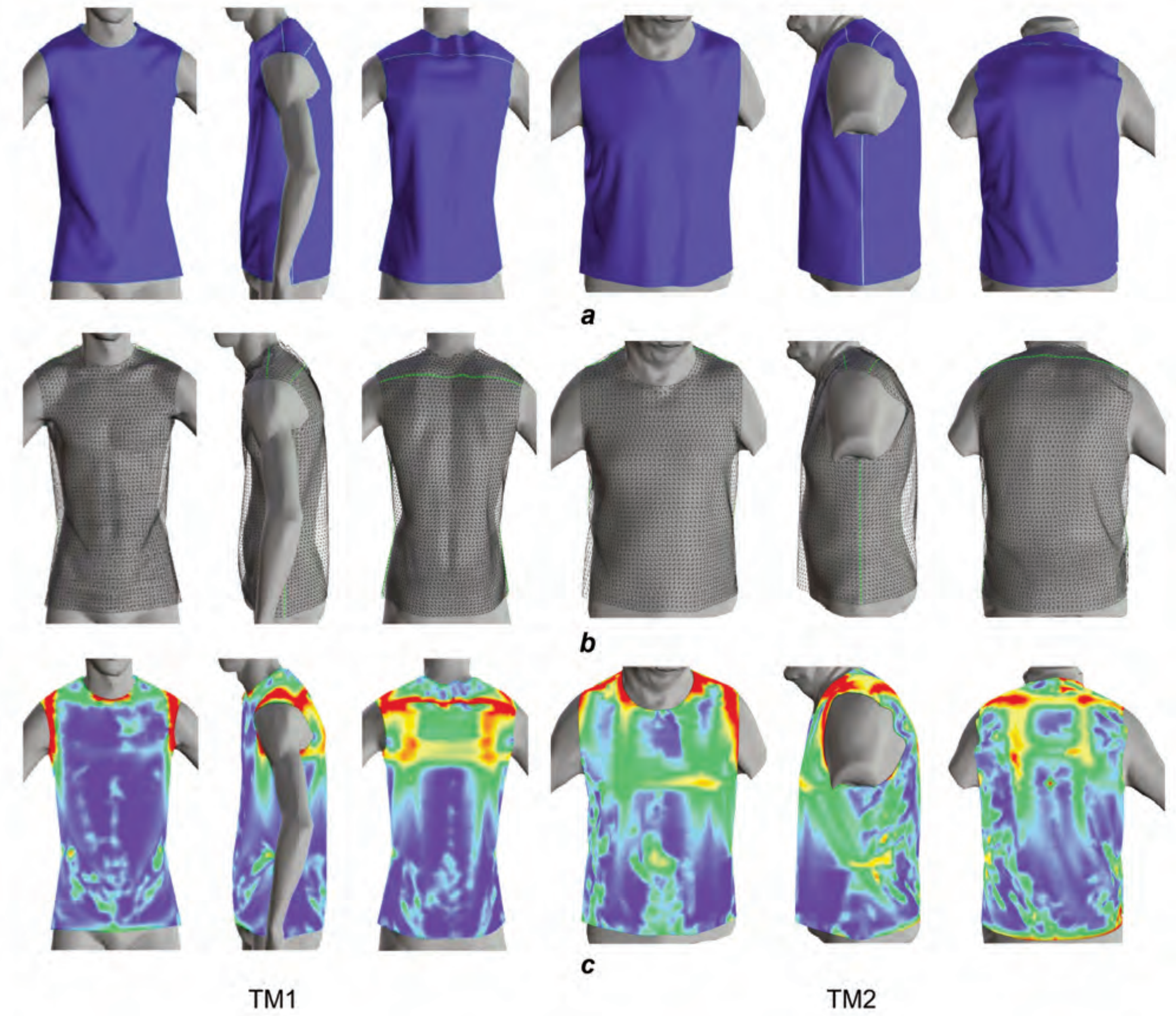


Fig. 7. Virtual fitting of the sleeveless basic shirts pattern designs to TM1 and TM2

Table 5

CASP EVALUATION OF THE BACK				
SPINE	TF1	TF2	TM1	TM2
C	6.25	6.54	6.87	8.13
A	1.19	1.05	1.26	1.19
S	56.28	19.85	39.39	21.35
P	0.99	1.08	1.00	1.34

parameter S (39.39) for TM1 compared to the TM2 (S = 21.35) arose from the scanning posture and asymmetrical arms posture.

Based on this part of the research it can be seen that both analyses, CASP evaluation and bodies shapes and postures observation give us similar conclusions. This means that CASP methodology and CASP values for surface analysis allows us to predict the degree of curvature of the spine (parameter C) and the symmetry of the body (parameter S), which should be considered in the process of garment pattern designs' adaptions to the body.

Adaption of garments to bodies' deformities and postures

The adaption of garments basic pattern designs according to bodies' deformities and postures were carried out to remove the discomfort of teens and adults when wearing garments (figures 9 and 10).

For the female teenager TF1 (strong breast, scoliosis, forward pushed upper part of shoulder blades), we adjusted the basic blouse pattern design only on the front part by increasing breasts girth for 2.0 cm on dimension of a breasts width and armhole width (figure 9). In this way, a decrease in the tension of the blouse around the breast and at the same time on the back part was achieved. Thus, an average tension of the blouse in relation to the body decreased from 7.42 fg/cm to 5.5 fg/cm.

For the adult female TF2, showing mild kyphosis and scoliosis, we adjusted the blouse basic pattern design to the body by moving the dart from the armhole to the back middle seam and curved the middle seam from the dart to the neckline (figure 9). When comparing figures 6 and 9, we can see that the tension

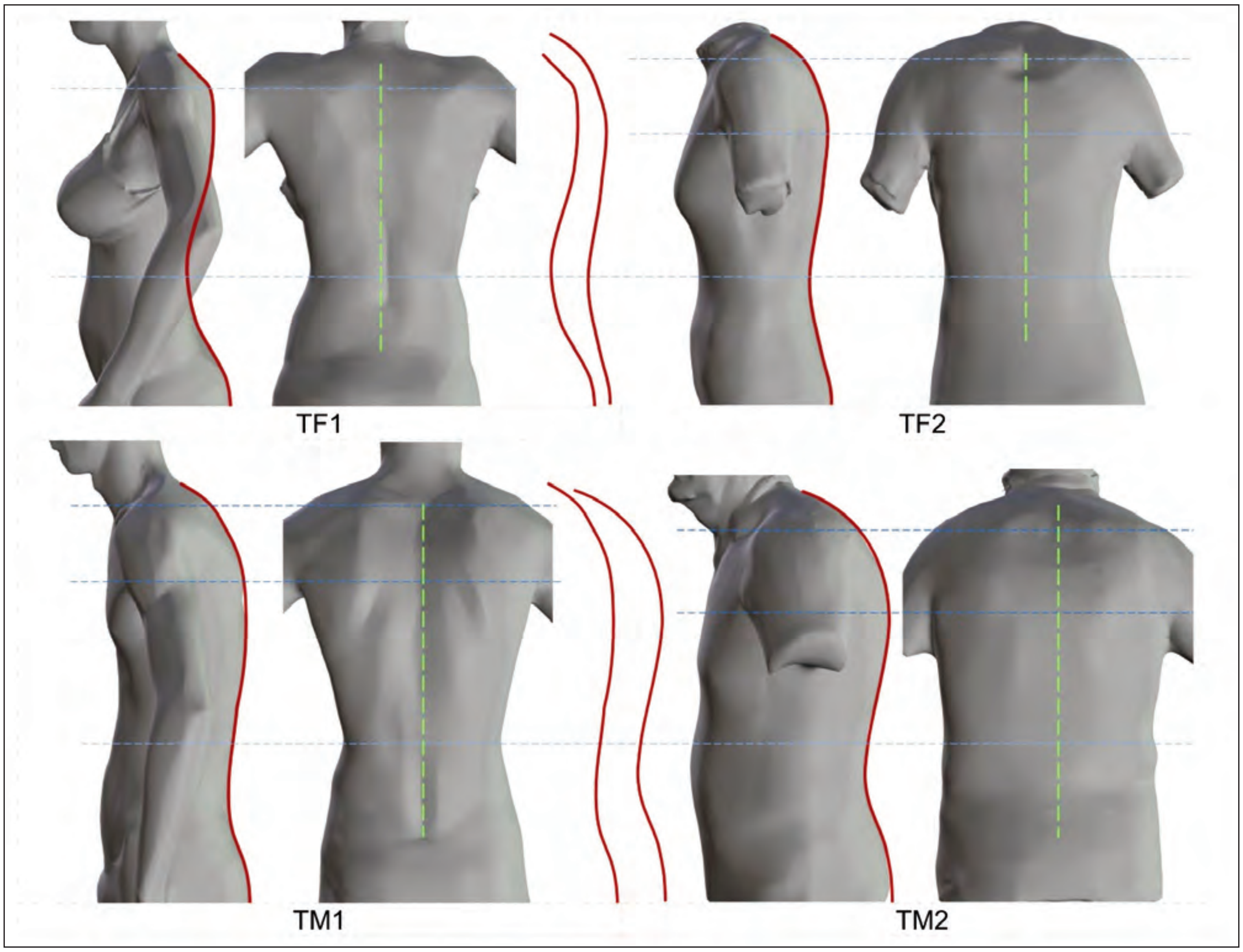


Fig. 8. Scanned persons' spine shapes and postures

in the blouse in the thoracic spine region was released, while the average blouse tension in relation to the body decreased from 11.54 fg/cm to 11.44 fg/cm.

3D simulations of the adapted shirts to TM1 and TM2 are presented in figure 10.

For both male tested persons (TM1, TM2) a decrease of tensions in shirts can be seen after their adaptions when comparing with shirts before adaption and in thoracic spine region, respectively (figures 7 and 10). An average tension was decreased for a teenager TM1 from 5.77 fg/cm to 4.64 fg/cm and for an adult from 8.65 fg/cm to 5.91 fg/cm. During adaption, yoke was omitted from the pattern pieces and the two back pattern pieces were constructed with darts in the middle seam. The dart that was positioned between the yoke and back bottom pattern piece was moved into the back middle seam in the position of the bottom region of the shoulder blades and greatest spine curvature, respectively. In addition, the back middle seam was curved from the dart to the neckline. For the tested person TM1 an armhole was also deepened for 1.5 cm.

In this research an improved garments' fitting to the bodies and higher wearing comfort, respectively, was obtained on the basis of the adaptation of the clothing to the perceived deformities of the spine. The survey showed that despite the construction of garments according to the actual dimensions of the tested persons and rules of the construction system, the clothing items did not fit well, which could cause wearing discomfort. Therefore, the constructed garments needed to be further adapted to individuals. With the help of CASP values and virtual prototyping, we found that for individuals suffering from kyphosis, the shoulder blades' darts should be moved from the armhole to the posterior middle seam and lowered to the line of the inferior point of the shoulder blade. Furthermore, the middle seam should be curved from the dart to the neckline.

CONCLUSIONS

This article is in line with the research carried out worldwide presenting the applications of virtual 3D simulation technology for testing and completion of clothing products for people with spine deformities. The research was conducted in order to ensure the body-garment correspondence for subjects with morphological features, which are different from the typical ones, such as spine deformity, and who are not able to purchase suitable clothing from the retail network.

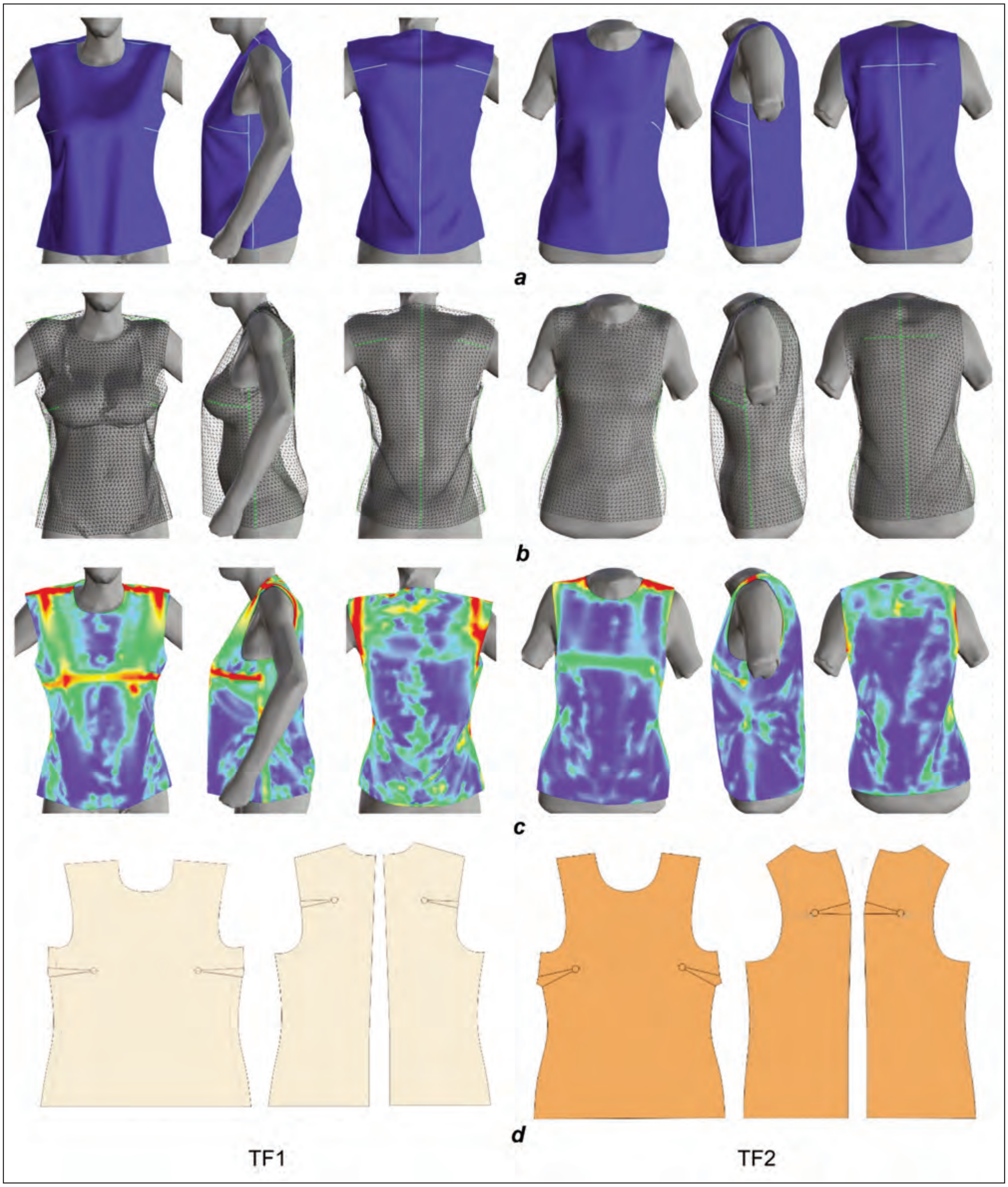


Fig. 9. Virtual fitting of the adapted sleeveless basic blouse pattern designs to TF1 and TF2

The research presents the use of advanced virtual tools and CASP methodology, which may be a useful tool in the procedure of adaption of the garments' pattern designs for people with spine deformity, especially kyphosis. The research regarding the usefulness of the CASP methodology for nonstandard body figures' garment pattern design showed that CASP methodology is adequate for predicting the appropriate garment pattern design for persons with a curved spine, especially kyphosis.

Based on the previous results, this research was focused on scanning the people, both adults and teenagers with spinal deformities, especially kyphosis and construction of the garment pattern designs for them. The results confirmed that the CASP methodology is adequate for defining the appropriate garment pattern design for persons with a curved spine. Namely, the CASP values enable us to assess the degree of kyphosis (parameter C – curvature) or scoliosis (parameter S – symmetry) to be able to

Fig. 10. Virtual fitting of the adapted sleeveless basic shirts pattern designs to TM1 and TM2

properly respond to the reconstruction of the garment pattern design.

The working methodology presented in this article can be used in the completion of the patterns for different degrees of kyphosis and clothing products by the professionals working in the clothing industry, so that people with atypical bodies can benefit from clothing products that will respond to a higher level of requirements imposed by specific shape of the body.

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