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Standard values of the upper body posture in female adults

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Abstract

Objective: Classifications of posture deviations are possible when compared to standard values. Standard values have been published for healthy male adults but are not known for female adults.

Design: Observational study.

Setting: Institute of Occupational Medicine, Social Medicine and Environmental Medicine, Goethe-University Frankfurt/Main.

Participants: 106 female healthy volunteers (21 - 30 years old; 25.1 ± 2.7 years) were included. Their body weight ranged from 46-106 kg (Ø 60.3 ± 7.9 kg), the heights from 1.53 to 1.82 m (1.69 ± 0.06 m), and the body mass index ranged from 16.9 kg/m² to 37.6 kg/m² (21.1 ± 2.6 kg/m²).

Outcome measures: A three-dimensional back scan was performed to quantify the upper back posture while habitual standing. The tolerance regions and the confidence interval were calculated. Group differences were tested by using the Wilcoxon-Mann-Whitney-U-test.

Results: The spinal column was marginally twisted to the left. The angle in the thoracic spine area is larger than that in the lumbar region. Consequently, a more kyphotic posture can be observed in the sagittal plane. The habitual posture is slightly scoliotic with a rotational component (scapular depression right, right scapula marginally more dorsally, high state of pelvic right, iliac right further rotated anteriorly).

Conclusions: Healthy young women have an almost ideally balanced posture with minimal ventral body inclination and a marginal scoliotic deviation. The comparison to equivalent data of young males shows only marginal differences in the upper body posture. These values allow a comparison of other studies for control and patient data, and may serve as orientation in both clinical practice and scientific studies.

Key words: body posture, back scan, standard value, female subjects

Strengths and limitations of this study

- One strength of this study is the large number of only female participants of the same age (21-30 years).
- Quantitative analysis of the upper back by using a videorasterstereografic approach.
- One limitation of the study is the measuring of the upper body posture only in habitual standing position and not while moving.
- Furthermore, external influences of the occupational environment were not assessed which might influence the body posture.

Introduction

Various subjective and objective methods quantify and analyze the body posture, especially the spinal posture. All methods aim to evaluate the degree of deformity in the diagnosis and treatment of spinal deformities like scoliosis [1-4].

Quantitative analytical methods enable the diagnosis of spinal curvature deviations and/or control the therapeutical effects. The methods vary by their technical complexity and clinical applicability. Roentgenograms or computed tomography scans are frequently used for the diagnosis of bone structure deformities, while ultrasound, inclinometer, thermal infared imaging, scoliometer or video raster stereography more often establish postural measurements [5-10]. X-ray based methods rarely may cause cancer or sperm cell mutations after repeated exposure but still are the gold standard in diagnosis and follow-up of body posture deviations [11-14].

Video raster stereography has recently been evaluated as an alternative method to measure and quantify vertebral column posture and its deformities [7 8 15-18]. Guidelines of orthopedic rehabilitation in Germany also recommended a follow-up check but do not specify the methods [19]. The three-dimensional back scan measures the body geometry between the 7th cervical vertebrum and the gluteal cleft, it has high intraclass correlation coefficients for its measurements and good Cronbach's Alpha values for intra- and interday reliability for all spine parameters [17 18 20 21]. Furthermore, inter tester reliability is high [17].

A three-dimensional surface contour image of the back appears suitable to determine vertebral column deformities, but also to quantify the effect of e.g. orthopedic shoe insoles on the body posture [22 23]. In addition, 3D images are used to give an insight into muscular imbalances (kyphotic / lordotic deviations, differences in waist contours, rotation in the shoulder or pelvis) and to control the effects and therapeutic success of muscle training in primary, secondary and tertiary prevention [24 25].

Due to the changing workplace environment with its increase in digital work, ever more employees work in a sitting position. Both in the workplace and in the household, this leads to a steady decrease in physical stress on the body. This lack of exercise consequently results in the fast development of muscular imbalances as well as an increase in the number of persons with back pain, as estimated for Germany at 20 million people [20] . Back pain complaints can also lead to disability or early retirement due to musculoskeletal disorders. Even more frequently, rehabilitation is required to restore the capacity to work in their original occupation.

Early signs of postural disorder e.g. musculoskeletal disorders should be detected after the development of subjective symptoms, and treated appropriately; in order to assess both diagnosis and treatment effects, quantitative classification criteria are necessary for normal posture and deviations hereof. These "deviations" should be quantified, e.g. in the form of (parametric or non-parametric) percentiles, similar to the Z- or T-scores of bone density [26]. However, standard or reference values of body posture currently are lacking for healthy female subjects; reference values of the upper body posture for healthy men are published recently [27]. Also, classifications of the severity of posture deviations are only possible with quantifiable deviations from standard or reference values.

Since standard values for the posture of healthy persons are lacking, this study aims to define reference values for the upper body posture in healthy women aged 21 - 30 years measured by a three dimensional back scan. These values and their variances define tolerance ranges of upper body posture and can be used to categorize the results of other (orthopaedic) studies. Investigating a homogeneous group of subjects eliminate constitutional, habitual and degenerative changes that could increase both tolerance range and confidence interval [28-31].

Methods

Subjects

106 female volunteers between 21 and 30 years old (25.1 ± 2.7 years) participated in this study. Their body weight ranged from 46-106 kg (60.3 ± 7.9 kg), the height from 1.53 to 1.82 m (1.69 ± 0.06 m), and the body mass index ranged from 16.9 kg/m² to 37.6 kg/m² (21.1 ± 2.6 kg/m²). According to the WHO weight classification [32] 6.6% of the participants were underweight (BMI < 18.5 kg/m^2), 87.8% of the participants had a normal BMI (18.5 to 24.9 kg/m²), 4.7% were overweight (BMI 25 to 29.9 kg/m²) and 0.9% had obesity I° (BMI 30 - 34.9 kg/m²).

All subjects were healthy and free of musculoskeletal complaints. With the help of a questionnaire temporomandibular system disorders were excluded [33] 95.3% of the subjects reported to be right-handed and 4.7% were left-handed. 72.6% of the participants were students, 27.4% were employees in different occupations (dentists, physicians, teachers, office workers).

All subjects were informed about the study design before giving written informed consent. The study was approved by the local medical ethics committee of the medical faculty (Goethe-University Frankfurt; No. 303/16).

Measurement system

A three-dimensional back scan was performed to quantify the upper back posture while standing, using the back scan system "MiniRot Kombi" (ABW GmbH, Frickenhausen/Germany).

In this system a projector forms a stripe pattern on the persons bare back; this stripe pattern was captured by a LCD camera from a defined angle. In this way the back surface was represented as a phase picture which was analyzed by an integrated software program reconstructing the 3D image. For calibration of the phase pictures all test persons were marked at six defined, standardized anatomical locations (Fig. 1) indicating underlying bone structures. One measurement lasts approx. 2 seconds. Artifacts may be caused by different patient placements or movements during the scan, i.e. the projection of the stripe pattern on the back, and thus have to be avoided. To measure the body posture, three repeat measurements were taken within 2 minutes.

Fig. 1

The six anatomical landmarks allow the calculation of three-dimensional parameters (Fig. 1) which include information about rotational movements in the shoulder and pelvic area and the shape of the spine (lordotic, kyphotic and/or scoliotic posture).

During a movement sequence 15 photos were taken. The maximum picture frequency of the MiniRot Kombi system is more than 50 frames/sec with a spatial resolution of 1/100 mm. The calculation of the three-dimensional coordinates of the back surface is performed by triangulation. The system error is specified as <1 mm (manufacturer information), the reproducibility is limited by the calculations of the upper body posture defined by markers directly on the skin (<0.5 mm).

Body scans

The subjects stood barefoot in their habitual body and jaw posture about 90 cm in front of the back scan apparatus. The arms were hanging loosely; the subjects looked horizontally fixing the opposite wall.

Evaluation Parameter

The three-dimensional back scan was split into three components to quantify the following parameters: spinal area (markers on C7 and L3), shoulder area (markers at the top of the left/right scapula) and pelvis area (markers on the left/right spina iliaca posterior superior [SIPS]). The marker positions are shown in Figure 1 and a list and the appropriate explanation of the spine parameters are shown in [27].

Statistical evaluation

The data evaluation was carried out using BIAS (Version 11.0) (Epsilon Verlag, Darmstadt, Germany). With the initial Kolmogorov-Smirnov-Test the normal distribution can only partly rejected, so that either parametrical tolerance regions or non-parametrical tolerance regions were calculated which were defined by the upper and lower limit for 95% of all values (approximately corresponding with +-2s values). These values have been found in about 95% of the examined subjects. Within this tolerance range all values are considered as normal so that the tolerance ranges estimate the central part of 95% of the value of the measured subject population.

Furthermore, the two-sided 95% confidence interval was calculated and indicated the range of the mean or median value – depending on the distribution quality – and showed the "accuracy" of these values. For testing group differences, the t-test or the Wilcoxon-Mann-Whitney-U-test was used.

Results

The constitutional parameters "body weight" and "BMI" were not normally distributed, only the constitutional parameter "body height" was normally distributed. The median of the body weight was 60 kg (tolerance range 49.0 to 77.28 kg; confidence interval 57 to 62 kg). For the BMI a median of 20.7 kg/m² was calculated, with a corresponding tolerance range from 17.99 to 27.2 kg/m² and a confidence interval from 20.3 to 21.3 kg/m². For the body height a mean value of 1.69 m was calculated with a tolerance range between 1.57 and 1.82 m and a confidence interval of 1.68 to 1.70 m.

The lack of handedness as a relevant parameter has been tested in advance by the t-test and the Wilcoxon-Mann-Whitney-U-test. All parameters were not significantly different ($p \geq 0.05$).

From the back scan values the posture of an average healthy female person was calculated (tab. 1). On average the subjects are standing slightly inclined in the anterior line of 3.31° (tolerance range 8.12° ventrally to 1.5° dorsally; confidence range 3.78° to the left to 2.85° to the right).

Laterally, a minimal deviation of the frontal trunk of 0.43° to the left was seen, the confidence interval (0.18° right – 0.67° left) included the perpendicular position, the tolerance interval ranged from 2.91° to the left and to 2.06° to the right. Compensatory, the axial deviation (as inclination between upper body and pelvis) was slightly tilted to the right (0.21°) with a tolerance range of approx. ±4.5° and a confidence interval of <1° (0.25° left and 0.66° right). This implied that there are no obvious differences in the inclination between the upper and lower body.

The angle of the thoracic bend was calculated from the distance between the vertebra prominens and the kyphosis apex and indicated the deviation from the perpendicular line. The median angle was 13.9° confirming the expected thoracic kyphosis. Here, wider variations were indicated by the tolerance range of 6.49° or 21.31°, and a confidence interval varying from 13.19° to 14.62°. The lumbar bending angle describes the deviation of the distance between the lordosis- and kyphosis apex. As compared to the thoracic bend, similar variations of the tolerance value and the confidence intervals were seen in the lumbar region, with a bending angle of 13.17° (tolerance value 7.83° to 23.06°; confidence interval 11.90° to 14.25°).

Measurement of the lateral deviation showed a right-sided inclination of the median line by 3.92° when connecting the points VP and the center of the pelvic markers. Both the tolerance range (0.50° respectively 7.33°) as well as the confidence interval (3.59°/4.25°) indicated a right-sided deviation.

The rotation of the spinal column is a torsion marker of the spinal column and can be measured from the spinous processes of the vertebrae. In our analysis, a negative value indicates a rotation to the left and a positive value to the right. The median rotation was 4.66°, with a tolerance range between 2.04° and 12.92°, and a confidence interval between 4.18° and 5.29°. Consequently, on average a right sided spinal rotation was found.

The next two parameters, the kyphosis and lordosis angle have a mean or a median of 51.66° and 46.29°, with a substantial tolerance range of approximately ±25° and a confidence interval of about ±2°.

Shoulder parameters are valid indicators for upper body posture (tab. 1), too. The lower scapula spinae were measured from the fixed markers; the scapula distance values as indicator of the variability of the upper body was 150.56 mm, with a tolerance range of 110.51 – 190.60 mm, and a confidence limit of 146.68 – 154.43 mm. The scapular height (deviation from the horizontal line) refers to a slightly lower left shoulder blade (by 1.28°), whereas the upper and lower limit of the range markers were -22.36° and 19.81°, so that the left shoulder blade is more caudally in the lower limit and more cranially in the upper limit. The same variation is shown by the data of the confidence interval, with values of -3.32 (left scapula higher) – 0.76 ° (right scapula higher).

The shoulder markers illustrated a right shoulder being slightly further dorsal by 3.06°, with a tolerance range of -3.26° to 9.37° and a confidence interval of 2.44° to 3.67°. Only minor differences between the left and right shoulder blade angle were seen, with the right shoulder 2.6° (median) more caudally.

Table 1 compiles the pelvis parameters. The distance for the spina iliaca posterior superior markers refers to the pelvic width, which on average is 99.56 mm (tolerance range 74.76 to 122.37 mm, confidence interval 97.17 and 101.96 mm).

The deviation of the pelvic height (in degrees) from the horizontal plane is very low. Both differences in pelvic height (in mm) and deviations from the horizontal line (in degrees) indicate a slightly higher position of the right pelvic side of approx. 1° or 1 mm (Tab. 4). The same applies to the pelvis torsion and rotation, so that the right iliac marker is rotated posteriorly and simultaneously tilted further ventral (mean pelvis torsion: 0.24 °; mean pelvic rotation: 2.2°).

Tab. 1

Discussion

This paper presents normal values and normal ranges (tolerance and confidence interval) for the body posture of healthy young females from different occupations. Height, weight and body mass index (BMI) of the participants are comparable to average young German female persons [34 35]. These parameters were measured by Mensink et al. [34] in over 7000 adults from the general German population. The age-matched female group was 3.20 cm smaller, 4.92 kg heavier and thus also had a BMI 2.58 kg/m² higher in comparison to our values. Similar findings have been reported by the German Federal Statistical Office in 2011 for the survey year of 2009 [35], which correlate even better to our results than the findings of Mensink et al.[34]. Data for height, weight and BMI, obtained to assess the prevalence of obesity in Germany between 1985 and 2002 [36] in 1504 female volunteers (25-29 years) show that the subjects in our study are marginal taller, lighter and have a lower BMI.

87.8% of the participants in this study have a normal BMI, 22.3% more than Mensink et al. [34] found for 18-29 year old women. The relation of overweight with social status is well known; this confounder of obesity is seen by the data from Mensink et al. [34] who proved that 36.9% women with a high social status suffered from overweight and 16.4% from obesity. Helmert et al. [36] calculated similar data with the equivalent household income; 31.8% of the people in the 4th and 5th quintile (low income) suffer from overweight and 7.8% from obesity. Thus the different BMI values likely are explained by the selection of many participants from the students of the School of Dentistry in our university, with a high social status (72.6%).

The back scan values indicate a characteristic posture of young females. Only small deviations from an ideal perpendicular position are noted; the marginally ventral tilt of the trunk, the lateral deviation and rotation of the spine, shoulder and pelvis were very small. The posture is marginally scoliotic (the ventral trunk tilts marginally to the left side, the scapula is higher on the left side, the pelvis is slightly elevated on the right side) with an expected rotatory component (a lumbar right tilt to compensate for the left tilted ventral trunk, a slight twist of the processus spinosus to the right, the right scapula marginally more dorsal, the SIPS of the right iliac bone rotated anteriorly) (Tab. 1). The spinal curve, defined by the thoracic and lumbar bending angle and the kyphosis and lordosis angle, indicates that the angle in the thoracic spine area is marginally larger than that in the lumbar region (Tab. 1), and consequently a slight kyphotic posture in the sagittal plane can be observed.

Handedness has no influence on these parameters, which should be expected from the observed symmetry. However, since 95.3% of the participants were right-handed no firm conclusions can be drawn for left handed people. Also, whether an influence of the dominated leg [37] exists on the posture of the present investigation can't be answered. Appropriate test methods for the determination of these components should be used in further studies.

A gender comparison for young healthy women and men [27] shows only marginal differences in the upper body posture. Both studies used the same measuring system and data evaluation and thus allow a direct comparison of the values. Although the female upper body appears narrower and more delicate due to the weaker muscular shoulder girdle and the smaller chest, the ratio between chest and shoulder width is the same [38].

The anatomical and constitutional differences are confirmed by the present data. In terms of the width of the shoulders, the fixed scapular landmarks indicate a larger distance of 2.9 cm in men than in women (Table 1). In contrast, men have a smaller pelvis calculated from the SIPS markers (6 mm difference). This results in a wider shoulder than pelvis distance by 8.5 cm in men, but only 5.0 cm in women, confirming and quantifying the well-known gender-specific anatomical differences.

In addition to these constitutional differences, differences in the lordotic and kyphotic angles are calculated from the spinal column parameters. Thus, women have an average kyphotic angle of 52°, men of 46°; the lordosis angle is 46° for women and 31° for men. Thus, the spinal curvature in the thoracic and lumbar spine area is more pronounced in women than in men. The difference in the lordosis angle is about 15° greater than in the case of the kyphotic angle with approximately 6°, however, men have an approximately 15° greater thoracic kyphosis angle than lumbar lordosis angle in contrast to a 6° difference of women.

Consequently, men have a larger kyphosis in the thoracic spine, with a corresponding lower lumbar lordosis.

Liu et al. [39] tried to define standard parameters of cervical spine alignment and range of motion related to age, sex, and cervical disc. These results underline the more pronounced thoracal kyphosis in women. The greater lumbar lordosis of the females can be traced back to sex differences in the pelvic shape. The wider female pelvic basin requires a larger angle between the pelvic bones and a larger and lower pelvic transverse diameter. Thus, the pronounced female pelvic tilt leads to a larger lumbar lordosis, which consequently causes a compensatory thoracal hyperkyphosis; these (different) compensations are seen above the pelvic position in both sexes [38]. This different position of the lumbar spine also affects the extent of the movement in the flexion-extension testing of the trunk. The total task-specific hip motion ranges, as measured from erect standing to the maximum flection, were higher in females than in males [40].

Furthermore, the same authors report that female chronic low back pain patients had higher regional hip and trunk motion ranges than male patients [41]. The question, why women have a larger lordosis angle currently is unanswered. An extensive literature search in PubMED and other data bases did not retrieve a published hypothesis. An explanation of physiological differences, however, has been forwarded to comparable sex differences in pelvic anatomy for rodents, and has been related to sexual behavior in these animals. Guinea pigs show hormonally controlled, gender related reproductive behaviour: male guinea pigs show a distinct sexual approach consisting of body raising, intromission and ejaculation, and female guinea pigs respond with a corresponding conceiving position of a predominantly lordotic lumbar posture [42] [43]. At least for this species the observed anatomical differences may translate directly into an apt reproductive behaviour. The pelvis itself has the same position in both sexes in a relaxed posture, and is positioned almost horizontally.

No similar explanation exists for differences in the shoulder region parameters; the right shoulder is positioned more caudal in both sexes, but women have “deeper” shoulders (increased scapular angle right/left).

All other parameters are nearly identical between men and women, with the differences smaller than the margin of error of our measurement, and thus have no clinical relevance.

The three-dimensional back scan is a fast, non-contact method to quantitate the body posture, and is suitable for measuring body postures in healthy persons and patients. It can quantify pathologic positions like scoliosis, kyphosis, leg length differences and functional movement disorders, as well as improvements obtained by medical treatments. The chances and limitations of the measurement system and procedure [44-50] has already been discussed by Ohlendorf et al. [27 51]. In the future, this method may allow to grade postural deviances, e.g. by a grading system using the tolerance ranges for men and women, as has been done for bone densitometry in the t- and z-scales [26].

Conclusion

Video raster stereography is a method to quantitatively measure the human three-dimensional back surface. Healthy young women have an almost ideally balanced posture with minimal ventral body inclination and a marginal scoliotic deviation. In comparison to age-matched men women have only small differences in upper body posture, with nearly identical normal values. These values allow a comparison of other studies for control and patient data, and may serve as orientation in both clinical practice and scientific studies. Further studies should expand this method to quantify age-related changes in body posture, as well as quantitative assessments of postural changes in relevant orthopedic diseases, and improvements by therapeutic interventions.

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a. contributorship statement

DO, FV, DC, SS, OG and SJ made substantial contributions to the conception and design of the manuscript, DO, FV and DC made substantial contributions to the construction of the measurement protocol and AH and DO has been involved in the statistical data analysis. All authors have read and approved the final manuscript.

b. competing interests

The authors declare that they have no conflict of interest.

c. funding

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d. data sharing statement

No additional data available.

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Tables

Tab. 1 Spine, shoulder and pelvis parameter: mean value, median, tolerance regions (upper and lower limit), confidence interval (left and right limit). Italic data are non-parametrical values.

	Mean value/ median	tolerance range lower limit	tolerance range upper limit	confidence interval left limit	confidence interval right limit
Spine parameter					
Trunk length D (mm)	461.31	412.95	509.67	456.64	465.99
Trunk length S (mm)	509.52	458.88	560.15	504.62	514.41
Sagittal trunk decline (°)	-3.31	-8.12	1.5	-3.78	-2.85
Frontal trunk decline (°)	-0.43	-2.91	2.06	-0.67	-0.18
Axis decline (°)	0.21	-4.45	4.86	-0.25	0.66
Thoracic bending angle (°)	13.9	6.49	21.31	13.19	14.62
Lumbar bending angle (°)	*13.17*	*7.83*	*23.06*	*11.9*	*14.25*
Standard deviation lateral deviation (mm)	3.92	0.5	7.33	3.59	4.25
Maximal lateral deviation (mm)	*-5.35*	*-12.8*	*12.38*	*-5.76*	*-0.89*
Standard deviation rotation (°)	*4.66*	*2.04*	*12.92*	*4.18*	*5.29*
Maximal rotation (°)	*9.2*	*-9*	*37.48*	*8*	*10.76*
Kyphosis angle (°)	51.66	27.91	74.42	49.37	53.96
Lordosis angle (°)	46.29	21.66	70.92	43.91	48.67
Shoulder parameter					
Scapular distance (mm)	150.56	110.51	190.6	146.68	154.43
Scapular height (°)	-1.28	-22.36	19.81	-3.32	0.76
Scapular rotation (°)	3.06	-3.26	9.37	2.44	3.67
Scapular angle left (°)	28.54	16.49	62.74	27.36	30.74
Scapula angle right (°)	31.17	10.61	73	27.2	34.62
Pelvis parameter					
Pelvis distance (mm)	99.56	74.76	124.37	97.17	101.96
Pelvis height (°)	0.76	-4.29	5.81	0.28	1.25
Pelvis height (mm)	1.34	-7.33	10.01	0.5	2.18
Pelvis torsion (°)	0.24	-6.89	7.36	-0.45	0.93
Pelvis rotation (°)	2.2	-5.72	7.34	1.49	2.76

Figure legend

Fig. 1: a) back scanner MiniRot Combi (ABW GmbH, Frickenhausen / Germany), b) three-dimensional phase picture of the back c) marker position on the back: A: Vertebra prominens (7th cervical vertebra), B: Lower scapular angle left, C : Lower Lower scapular angle right, D: Spina Iliaca Posterior Superior (SIPS) left , e: Spina Iliaca Posterior Superior (SIPS) right, F: Sacrum-point (cranial beginning of the gluteal cleft).

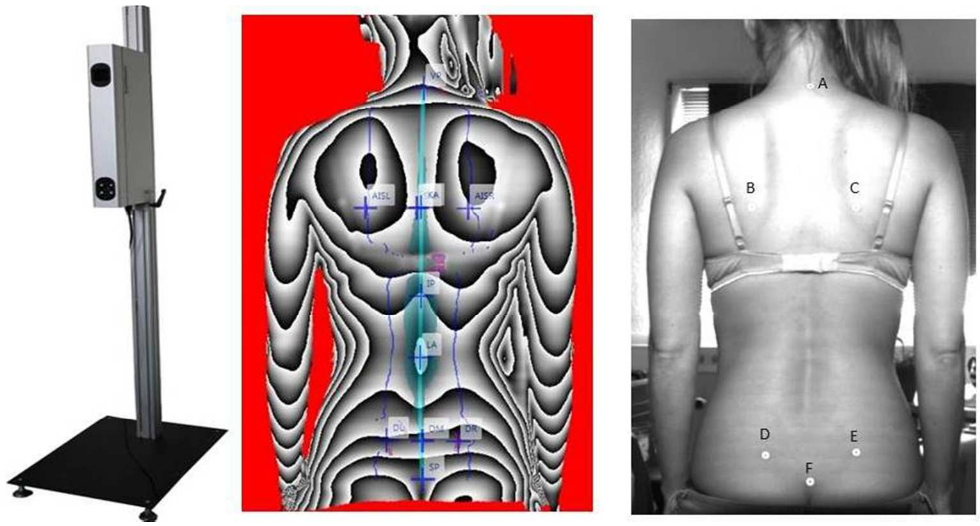

Fig. 1: a) back scanner MiniRot Combi (ABW GmbH, Frickenhausen / Germany), b) three-dimensional phase picture of the back c) marker position on the back: A: Vertebra prominens (7th cervical vertebra), B: Lower scapular angle left, C : Lower Lower scapular angle right, D: Spina Iliaca Posterior Superior (SIPS) left , e: Spina Iliaca Posterior Superior (SIPS) right, F: Sacrum-point (cranial beginning of the gluteal cleft).

248x128mm (96 x 96 DPI)

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Pages
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	4,6-8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-8
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	6
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	n/a
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-8
Bias	9	Describe any efforts to address potential sources of bias	n/a
Study size	10	Explain how the study size was arrived at	6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8
		(*b*) Describe any methods used to examine subgroups and interactions	n/a
		(*c*) Explain how missing data were addressed	n/a
		(*d*) If applicable, explain how loss to follow-up was addressed	n/a
		(*e*) Describe any sensitivity analyses	n/a
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	n/a
		(b) Give reasons for non-participation at each stage	n/a
		(c) Consider use of a flow diagram	n/a
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8-9
		(b) Indicate number of participants with missing data for each variable of interest	n/a
		(c) Summarise follow-up time (eg, average and total amount)	n/a
Outcome data	15*	Report numbers of outcome events or summary measures over time	9-11
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9-11
		(*b*) Report category boundaries when continuous variables were categorized	9-11
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9
Discussion			
Key results	18	Summarise key results with reference to study objectives	11-15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of	11-14

		analyses, results from similar studies, and other relevant evidence	
Generalisability	21	Discuss the generalisability (external validity) of the study results	14-15
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	2

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

n/a = not applicable

Since the study investigated healthy young women in an observational study these parts of the STROBE-criteria are not applicable.

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Standard values of the upper body posture in healthy young female adults, reference values for pathological changes

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Standard values of the upper body posture in healthy young female adults, reference values for pathological changes

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Abstract

Objective: Classifications of posture deviations are only possible compared to standard values. However, standard values have been published for healthy male adults but not for female adults.

Design: Observational study.

Setting: Institute of Occupational Medicine, Social Medicine and Environmental Medicine, Goethe-University Frankfurt/Main.

Participants: 106 female healthy volunteers (21 - 30 years old; 25.1 ± 2.7 years) were included. Their body weight ranged from 46-106 kg (60.3 ± 7.9 kg), the heights from 1.53 to 1.82 m (1.69 ± 0.06 m), and the body mass index from 16.9 kg/m² to 37.6 kg/m² (21.1 ± 2.6 kg/m²).

Outcome measures: A three-dimensional back scan was performed to measure the upper back posture in habitual standing. The tolerance ranges and confidence interval were calculated. Group differences were tested by the Wilcoxon-Mann-Whitney-U-test.

Results: In normal posture the spinal column was marginally twisted to the left and the vertebrae were marginally rotated to the right. The kyphosis angle is larger than the lumbar angle. Consequently, a more kyphotic posture is observed in the sagittal plane. The habitual posture is slightly scoliotic with a rotational component (scapular depression right, right scapula marginally more dorsally, high state of pelvic right, iliac right further rotated anteriorly).

Conclusions: Healthy young women have an almost ideally balanced posture with minimal ventral body inclination and a marginal scoliotic deviation. Compared to young males, women show only marginal differences in the upper body posture. These values allow a comparison to other studies, both for control and patient data, and may serve as guideline in both clinical practice and scientific studies.

Key words: body posture, back scan, standard value, female subjects

Strengths and limitations of this study

- Strength: large number of healthy young female participants aged 21-30 years.
- Strength: Videoraster-stereografic quantitative analysis of the upper back posture.
- Limitation: measurement of the upper body posture only in habitual standing position, not while moving.
- Limitation: external influences (occupational environment) were not assessed which might influence the body posture.

Introduction

Various subjective and objective methods to quantify and analyze the body posture have been used, especially for the spinal posture. All prior methods tried to evaluate deformity in the diagnosis and treatment of spinal diseases like scoliosis [1-4].

Quantitative analytical methods enable the diagnosis of spinal curvature deviations and/or control the therapeutic effects. The methods vary by their technical complexity and clinical applicability. Roentgenograms or computed tomography scans are frequently used for bone structure deformities, while ultrasound, inclinometer, thermal infared imaging, scoliometer or video raster stereography are established postural measurement methods [5-10]. X-ray based methods despite their mutagenic potential still are the gold standard in diagnosis and follow-up of body posture deviations [11-14].

Video raster stereography has recently been evaluated as an alternative method to quantify vertebral column posture and its deformities [7 8 15-18]. Guidelines for orthopedic rehabilitation in Germany also recommend a follow-up check but do not specify the methods [19]. The three-dimensional back scan measures the body geometry between the 7th cervical vertebrum and the gluteal cleft, it has high intraclass correlation coefficients and good Cronbach's Alpha values for intra- and interday reliability for all spine parameters [17 18 20 21]. Furthermore, inter tester reliability is high [17].

A three-dimensional surface contour image of the back appears suitable to determine vertebral column deformities, but also to quantify the effect of e.g. orthopedic shoe insoles on the body posture [22 23]. In addition, 3D images can quantify muscular imbalances (kyphotic / lordotic deviations, differences in waist contours, rotation in the shoulder or pelvis) and control the therapeutic success of muscle training in primary, secondary and tertiary prevention [24 25].

Due to the changing workplace environment with its increase in digital work, ever more employees work in a sitting position. Both in the workplace and in the household, this leads to a steady decrease of physical stress on the body. This lack of exercise may result in the development of muscular imbalances and increasing numbers of persons with back pain, currently estimated at 20 million people for Germany [20]. Back pain complaints due to musculoskeletal disorders can lead to disability or early retirement. Even more frequently, rehabilitation is required to restore the capacity to work in their original occupation.

Early signs of postural disorder e.g. musculoskeletal imbalances should be detected when subjective symptoms have developed, and treated appropriately; in order to assess both diagnosis and treatment effects, quantitative classification criteria are necessary for deviations from normal posture. These deviations should be quantified, e.g. in the form of (parametric or non-parametric) percentiles, similar to the Z- or T-scores of bone density [26]. However, no standard or reference values for body posture currently are published for healthy female subjects; reference values of the upper body posture for healthy men have been published only recently [27]. Also, classifications of the severity of posture deviations are only possible when deviations from standard or reference values are quantified.

This study measures the upper body posture in healthy women aged 21 - 30 years by a three dimensional back scan to provide standard values for the posture of young healthy women. These values and their variances define the normal upper body posture and its variability and may be used to categorize the results of other (orthopaedic) studies. Investigating a homogeneous group of subjects eliminate constitutional, habitual and degenerative changes that could increase both tolerance ranges and confidence intervals [28-31].

Methods

Subjects

106 female volunteers between 21 and 30 years (25.1 ± 2.7 years) participated in this study. Their body weight ranged from 46-106 kg (60.3 ± 7.9 kg), the height from 1.53 to 1.82 m (1.69 ± 0.06 m), and the body mass index ranged from 16.9 kg/m^2 to 37.6 kg/m^2 (21.1 ± 2.6 kg/m^2). 6% of the participants were underweight (BMI < 18.5 kg/m^2), 87.8% of the participants had a normal BMI (18.5 to 24.9 kg/m^2), 4.7% were overweight (BMI 25 to 29.9 kg/m^2) and 0.9% had obesity I° (BMI 30 - 34.9 kg/m^2) according to the WHO weight classification [32] .

All subjects were healthy and free of musculoskeletal complaints and therefore no patient were involved. Using a questionnaire temporomandibular system disorders were excluded [33] ; 95.3% of the subjects reported to be right-handed and 4.7% were left-handed. 72.6% of the participants were students, 27.4% employees in different occupations (dentists, physicians, teachers, office workers).

All volunteers were informed about the study design before giving written informed consent. The study was approved by the local medical ethics committee of the medical faculty (Goethe-University Frankfurt; No. 303/16).

Measurement system

A three-dimensional back scan was performed to quantify the upper back posture while standing, using the back scan system "MiniRot Kombi" (ABW GmbH, Frickenhausen/Germany).

In this system a projector forms a stripe pattern on the persons bare back; this stripe pattern is captured by a LCD camera from a defined angle. One measurement lasts approx. 2 seconds. In this way the back surface is represented as a phase picture which is analyzed by an integrated software program reconstructing the 3D image. For calibration of the phase pictures all test persons are marked at six defined, standardized anatomical locations (Fig. 1) indicating underlying bone structures. These allow the calculation of three-dimensional parameters (Fig. 1) with information about rotational movements in the shoulder and pelvic area and the shape of the spine (lordotic, kyphotic and/or scoliotic posture). Artifacts may be caused by different marker placements or movements during the scan, i.e. the projection of the stripe pattern on the back, and thus have to be avoided. To measure the body posture, three repeat measurements are taken within 2 minutes.

Fig. 1

During a movement sequence 15 photos were taken. The maximum picture frequency of the MiniRot Kombi system is more than 50 frames/sec with a spatial resolution of 1/100 mm. The calculation of the three-dimensional coordinates of the back surface is performed by triangulation. The system error is specified as <1 mm (manufacturer information), the reproducibility is limited by the calculations of the upper body posture defined by markers directly on the skin (<0.5 mm).

Body scans

The subjects stood barefoot in their habitual body and jaw posture about 90 cm in front of the back scan apparatus. The arms were hanging loosely; the subjects looked horizontally fixing the opposite wall.

Evaluation Parameter

From the three-dimensional back scan three components were quantified: spinal area (markers on C7 and L5), shoulder area (markers at the top of the left/right scapula) and pelvis area (markers on the left/right spina iliaca posterior superior [SIPS]). The marker positions are shown in Figure 1, the spine parameters are selected and calculated as described in [27].

Statistical evaluation

All calculations were carried out using BIAS (Version 11.0) (Epsilon Verlag, Darmstadt, Germany). Parameter distribution was tested by the Kolmogorov-Smirnov-Test indicating only partially normal distribution; parametrical or non-parametrical tolerance regions were calculated as defined by the upper and lower limit for 95% of all values (+-2 SD values), being found in > 95% of the examined subjects. Values within this range are considered “normal”.

Furthermore, the two-sided 95% confidence interval was calculated and indicated the range of the mean or median value – depending on the distribution quality – and showed the "accuracy" of these values. For group differences, the t-test or the Wilcoxon-Mann-Whitney-U-test was used.

<u>Results</u>

Only the constitutional parameter "body height" was normally distributed, whereas "body weight" and "BMI" were not. The median body weight was 60 kg (tolerance range 49.0 to 77.28 kg; confidence interval 57 to 62 kg). For the BMI a median of 20.7 kg/m² was calculated, with a corresponding tolerance range from 17.99 to 27.2 kg/m² and a confidence interval from 20.3 to 21.3 kg/m². For the body height a mean value of 1.69 m was calculated with a tolerance range between 1.57 and 1.82 m and a confidence interval of 1.68 to 1.70 m.

Handedness as a relevant parameter had been refused in advance by the t-test and the Wilcoxon-Mann-Whitney-U-test. All parameters were not significantly different ($p \geq 0.05$).

From the back scan values the posture of an average healthy female person was calculated (tab. 1). On average the subjects are standing slightly inclined in the anterior line of 3.31° (tolerance range 8.12° ventrally to 1.50° dorsally; confidence range 3.78° to the left to 2.85° to the right).

Laterally, a minimal deviation of the frontal trunk of 0.43° to the left was seen, the confidence interval (0.18° right – 0.67° left) included the perpendicular position; the tolerance interval ranged from 2.91° to the left to 2.06° to the right. In compensation the axial deviation (inclination between upper body and pelvis) was slightly tilted to the right (0.21°) with a tolerance range of ±4.5° and a confidence interval of <1° (0.25° left and 0.66° right). This implied that there are no obvious differences in the inclination between the upper and lower body.

The angle of the thoracic bend was calculated from the distance between the vertebra prominens (VP) and the kyphosis apex and indicated the deviation from the perpendicular line. The median angle was 13.9° confirming the expected thoracic kyphosis. Here, wider variations were seen with a tolerance range from 6.49° to 21.31°, and a confidence interval varying from 13.19° to 14.62°. The lumbar bending angle describes the deviation of the distance between the lordosis and kyphosis apex. As compared to the thoracic bend, similar variations of the tolerance value and the confidence intervals were seen in the lumbar region, with a bending angle of 13.17° (tolerance value 7.83° to 23.06°; confidence interval 11.90° to 14.25°).

Measurement of the lateral deviation showed a right-sided inclination of the median line by 3.92° when connecting the points VP and the center of the pelvic markers. Both the tolerance range (0.50°and 7.33° respectively), as well as the confidence interval (3.59°/4.25°) indicated a right-sided deviation.

The rotation of the spinal column is a marker of the spinal column torsion and can be measured from the spinal processes. In our analysis, a negative value indicates a rotation to the left and a positive value to the right. The median rotation was 4.66°, with a tolerance range between 2.04° and 12.92°, and a confidence interval between 4.18° and 5.29°. Consequently, on average a right sided spinal rotation was found.

The kyphosis and lordosis angle have a mean or a median of 51.66° and 46.29°, with a substantial tolerance range of approximately ±25° and a confidence interval of about ±2°.

Shoulder parameters are valid indicators for upper body posture (tab. 1), too. The lower scapular spinae were measured by fixed markers; the interscapular distance as indicator of the variability of the upper body was 150.56 mm, with a tolerance range of 110.51 – 190.60 mm, and a confidence limit of 146.68 – 154.43 mm. The scapular height (deviation from the horizontal line) refers to a slightly lower left shoulder blade (by 1.28°), whereas the upper and lower limit of the range markers were -22.36° and 19.81°, so that the left shoulder blade is more caudally in the lower limit and more cranially in the upper limit. The same variation is shown by the data of the confidence interval, with values of -3.32 (left scapula higher) – 0.76 ° (right scapula higher).

The shoulder markers illustrated a right shoulder being slightly further dorsal by 3.06°, with a tolerance range of -3.26° to 9.37° and a confidence interval of 2.44° to 3.67°. Only minor differences were seen between the left and right shoulder blade angles, with the right shoulder 2.6° (median) more caudally.

Table 1 also compiles the pelvic parameters. The distance for the spina iliaca posterior superior markers refers to the pelvic width, which on average is 99.56 mm (tolerance range 74.76 to 122.37 mm, confidence interval 97.17 and 101.96 mm).

The deviation of the pelvic height (in degrees) from the horizontal plane is very low. Both differences in pelvic height (in mm) and deviations from the horizontal line (in degrees) indicate a slightly higher position of the right pelvis by approx. 1° or 1 mm (Tab. 4). The same applies to the pelvic torsion and rotation, so that the right iliac marker is rotated posteriorly and simultaneously tilted further ventral (mean pelvis torsion: 0.24 °; mean pelvic rotation: 2.2°).

Tab. 1

Discussion

This paper presents normal values and normal ranges including tolerance and confidence intervals for the body posture of healthy young females. Height, weight and body mass index (BMI) of the participants are comparable to average young German female persons [34 35]. as measured by Mensink et al. [34] in over 7000 adults from the general German population. The age-matched female group from Mensink et al. [34] was 3.20 cm smaller, 4.92 kg heavier and thus also had a slightly higher BMI by 2.58 kg/m² as compared to our values. Similar findings have been reported by the German Federal Statistical Office in 2011 for 2009 [35], which correlate even better to our results.[34]. Data for height, weight and BMI, obtained to assess the prevalence of obesity in Germany between 1985 and 2002 [36] in 1504 female volunteers (25-29 years) show that the subjects in our study are marginal taller, lighter and have a lower BMI.

In this context, however, it should be borne in mind that this study mainly involved students and university employees with the same lifestyle, with values slightly differing from the general population, and a likely overrepresentation of participants with a high social status. 87.8% of the participants in this study have a normal BMI, 22.3% more than Mensink et al. [34] found for 18-29 year old women. The relation of overweight with social status is well known; this confounder is also seen by the data from Mensink et al. [34] ; 36.9% of women with a low social status were overweight, 16.4% obese as compared to 18.7% overweight and 4.4% obese women with a high social status. Helmert et al. [36] calculated similar data using the equivalent household income; thus the different BMI values likely are explained by the participant selection preferentially from the students of the School of Dentistry in our university, with a high social status.

The back scan values indicate a characteristic posture of young females. Only small deviations from an ideal perpendicular position are noted; the ventral tilt of the trunk, the lateral deviation and rotation of the spine, shoulder and pelvis were very small. The posture is marginally scoliotic (the ventral trunk tilts marginally to the left side, the scapula is higher on the left side, the pelvis slightly elevated on the right side) with an expected rotatory component (a lumbar right tilt to compensate for the left tilted ventral trunk, a slight twist of the processus spinosus to the right, the right scapula marginally more dorsal, the SIPS of the right iliac bone rotated anteriorly) (Tab. 1). The spinal curve, defined by the thoracic and lumbar bending angle and the kyphosis and lordosis angle, indicates that the angle in the thoracic spine area is marginally larger than that in the lumbar region (Tab. 1), and a slightly kyphotic posture in the sagittal plane can be observed.

Handedness has no influence on these parameters, which should be expected from the observed symmetry. However, since 95.3% of the participants were right-handed no firm conclusions can be drawn for left handed people. Also, whether an influence of the dominant leg [37] exists on the posture cannot be answered by our results. Appropriate test methods for the determination of these components should be used in further studies.

A gender comparison [27] shows only marginal differences in the upper body posture. Both studies used the same measurement system and data evaluation and thus allow a direct comparison of the values. Although the female upper body appears narrower and more delicate due to the weaker muscular shoulder girdle and the smaller chest, the ratio between chest and shoulder width is the same [38].

The anatomical and constitutional differences are confirmed by the present data. In terms of the shoulder width, the fixed scapular landmarks indicate a larger distance of 2.9 cm in men than in women (Table 1). In contrast, men have a smaller pelvis calculated from the SIPS markers (6 mm difference) which results in a wider shoulder than pelvis distance by 8.5 cm in men, but only 5.0 cm in women, confirming and quantifying the well-known gender-specific anatomical differences.

In addition to these constitutional differences, differences in the lordotic and kyphotic angles are calculated from the spinal column parameters. Thus, women have an average kyphotic angle of 52°, men of 46°; the lordosis angle is 46° for women and 31° for men. Thus, the spinal curvature in the thoracic and lumbar spine area is more pronounced in women than in men. The difference in the lordosis angle between the sexes is about 15° and in the case of the kyphotic angle with approximately 6°, however, men have an approximately 15° greater thoracic kyphosis angle than lumbar lordosis angle in contrast to a 6° difference of women. Consequently, the kyphosis angle is larger than the lordosis angle in both sexes, women are in a more balanced posture due to the smaller difference between the two angles.

Liu et al. [39] tried to define standard parameters of cervical spine alignment and range of motion related to age, sex, and cervical disc. These results underline the more pronounced thoracal kyphosis in women. The greater lumbar lordosis of the females can be traced back to sex differences in the pelvic shape: The wider pelvic blades of the female pelvis have a larger angle between the pubic branches, a larger transverse pelvic diameter and are lower. Thus, the pronounced female pelvic tilt leads to a larger lumbar lordosis. Consequently, a larger lumbar lordosis causes a thoracal hyperkyphosis. These (different) compensations are seen in the pelvic position in both sexes [38]. This position of the lumbar spine also affects the extent of the movement in the flexion-extension testing of the trunk. The total task-specific hip motion ranges as measured from erect standing to the maximum flection were higher in females than in males [40].

Furthermore, the same authors report that female chronic low back pain patients had higher regional hip and trunk motion ranges than male patients [41]. Why women have a larger lordosis angle currently is unknown. An extensive literature search in PubMED and other data bases did not retrieve any published hypothesis. An explanation of physiological differences, however, has been forwarded to comparable sex differences in the pelvic anatomy for rodents and has been related to sexual behavior in these animals. Guinea pigs show hormonally controlled, gender related reproductive behaviour: male guinea pigs show a distinct sexual approach consisting of body raising, intromission and ejaculation, and female guinea pigs respond with a corresponding conceiving position of a predominantly lordotic lumbar posture [42 43]. At least for this species the observed anatomical differences may translate directly into an apt reproductive behaviour. In both species, the pelvis itself has the same position in both sexes in a relaxed posture, and is positioned almost horizontally.

No similar explanation exists for differences in the shoulder region parameters either; the right shoulder is positioned more caudal in both sexes, but women have "deeper" shoulders (increased scapular angle right/left).

All other positional parameters are nearly identical between men and women, with the differences being smaller than the margin of error, and likely have no clinical relevance.

The three-dimensional back scan is a fast, non-contact method to quantify the body posture and is suitable for measuring body postures in both healthy persons and patients. It can quantify pathologic positions like scoliosis, kyphosis, leg length differences and functional movement disorders, as well as improvements by medical treatment. The chances and limitations of the measurement system and procedure [44-50] has already been discussed by Ohlendorf et al. [27 51]. In the future, this method may allow to grade postural deviations, e.g. by a grading system using the tolerance ranges for men and women, as has been done for bone densitometry in the t- and z-scales [26].

Conclusion

Video raster stereography is a method to quantitatively measure the human three-dimensional back surface. Healthy young women have an almost ideally balanced posture with minimal ventral body inclination and a marginal scoliotic deviation. In comparison to men women have only small differences in upper body posture, with nearly identical normal values. These values allow a quantitative comparison with other studies for control and patient data, and may serve as an orientation in both clinical practice and scientific studies. Further studies could expand this method to age-related changes in body posture, quantitative assessments of postural changes in relevant diseases, and improvements by therapeutic interventions.

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a. contributorship statement

DO, VF, CD, SS, GO and JS made substantial contributions to the conception and design of the manuscript, DO, VF and CD made substantial contributions to the construction of the measurement protocol and HA and DO have been involved in the statistical data analysis. All authors have read and approved the final manuscript.

b. competing interests

The authors declare that they have no conflict of interest.

c. funding

There is no external funding of the project.

d. data sharing statement

No additional data available.

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Tables

Tab. 1 Spine, shoulder and pelvis parameter: mean value, median, tolerance regions (upper and lower limit), confidence interval (left and right limit). Italic data are non-parametrical values.

	Mean value/ median	tolerance range lower limit	tolerance range upper limit	confidence interval left limit	confidence interval right limit
Spine parameter					
Trunk length D (mm)	461.31	412.95	509.67	456.64	465.99
Trunk length S (mm)	509.52	458.88	560.15	504.62	514.41
Sagittal trunk decline (°)	-3.31	-8.12	1.5	-3.78	-2.85
Frontal trunk decline (°)	-0.43	-2.91	2.06	-0.67	-0.18

Axis decline (°)	0.21	-4.45	4.86	-0.25	0.66
Thoracic bending angle (°)	13.9	6.49	21.31	13.19	14.62
Lumbar bending angle (°)	*13.17*	*7.83*	*23.06*	*11.9*	*14.25*
Standard deviation lateral deviation (mm)	3.92	0.5	7.33	3.59	4.25
Maximal lateral deviation (mm)	*-5.35*	*-12.8*	*12.38*	*-5.76*	*-0.89*
Standard deviation rotation (°)	*4.66*	*2.04*	*12.92*	*4.18*	*5.29*
Maximal rotation (°)	*9.2*	*-9*	*37.48*	*8*	*10.76*
Kyphosis angle (°)	51.66	27.91	74.42	49.37	53.96
Lordosis angle (°)	46.29	21.66	70.92	43.91	48.67
Shoulder parameter					
Scapular distance (mm)	150.56	110.51	190.6	146.68	154.43
Scapular height (°)	-1.28	-22.36	19.81	-3.32	0.76
Scapular rotation (°)	3.06	-3.26	9.37	2.44	3.67
Scapular angle left (°)	28.54	16.49	62.74	27.36	30.74
Scapula angle right (°)	31.17	10.61	73	27.2	34.62
Pelvis parameter					
Pelvis distance (mm)	99.56	74.76	124.37	97.17	101.96
Pelvis height (°)	0.76	-4.29	5.81	0.28	1.25
Pelvis height (mm)	1.34	-7.33	10.01	0.5	2.18
Pelvis torsion (°)	0.24	-6.89	7.36	-0.45	0.93
Pelvis rotation (°)	2.2	-5.72	7.34	1.49	2.76

Figure legend

Fig. 1: a) back scanner MiniRot Combi (ABW GmbH, Frickenhausen / Germany), b) three-dimensional phase picture of the back c) marker position on the back: A: Vertebra prominens (7th cervical vertebra), B: Lower scapular angle left, C : Lower Lower scapular angle right, D: Spina Iliaca Posterior Superior (SIPS) left , e: Spina Iliaca Posterior Superior (SIPS) right, F: Sacrum-point (cranial beginning of the gluteal cleft).

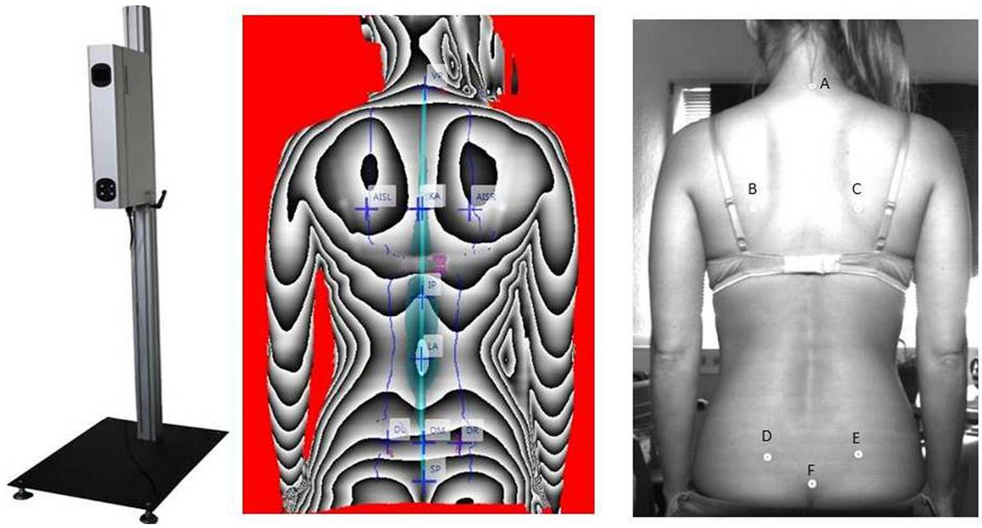

Fig. 1: a) back scanner MiniRot Combi (ABW GmbH, Frickenhausen / Germany), b) three-dimensional phase picture of the back c) marker position on the back: A: Vertebra prominens (7th cervical vertebra), B: Lower scapular angle left, C : Lower Lower scapular angle right, D: Spina Iliaca Posterior Superior (SIPS) left , e: Spina Iliaca Posterior Superior (SIPS) right, F: Sacrum-point (cranial beginning of the gluteal cleft).

199x103mm (300 x 300 DPI)

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Pages
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	4,6-8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-8
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	6
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	n/a
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-8
Bias	9	Describe any efforts to address potential sources of bias	n/a
Study size	10	Explain how the study size was arrived at	6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8
		(*b*) Describe any methods used to examine subgroups and interactions	n/a
		(*c*) Explain how missing data were addressed	n/a
		(*d*) If applicable, explain how loss to follow-up was addressed	n/a
		(*e*) Describe any sensitivity analyses	n/a
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	n/a
		(b) Give reasons for non-participation at each stage	n/a
		(c) Consider use of a flow diagram	n/a
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8-9
		(b) Indicate number of participants with missing data for each variable of interest	n/a
		(c) Summarise follow-up time (eg, average and total amount)	n/a
Outcome data	15*	Report numbers of outcome events or summary measures over time	9-11
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9-11
		(*b*) Report category boundaries when continuous variables were categorized	9-11
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9
Discussion			
Key results	18	Summarise key results with reference to study objectives	11-15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of	11-14

		analyses, results from similar studies, and other relevant evidence	
Generalisability	21	Discuss the generalisability (external validity) of the study results	14-15
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	2

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

n/a = not applicable

Since the study investigated healthy young women in an observational study these parts of the STROBE-criteria are not applicable.

BMJ Open

Standard reference values of the upper body posture in healthy young female adults in Germany: an observational study

Journal:	*BMJ Open*
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Standard reference values of the upper body posture in healthy young female adults in Germany: an observational study

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Abstract

Objective: Classifications of posture deviations are only possible compared to standard values. However, standard values have been published for healthy male adults but not for female adults.

Design: Observational study.

Setting: Institute of Occupational Medicine, Social Medicine and Environmental Medicine, Goethe-University Frankfurt/Main.

Participants: 106 female healthy volunteers (21 - 30 years old; 25.1 ± 2.7 years) were included. Their body weight ranged from 46-106 kg (60.3 ± 7.9 kg), the heights from 1.53 to 1.82 m (1.69 ± 0.06 m), and the body mass index from 16.9 kg/m² to 37.6 kg/m² (21.1 ± 2.6 kg/m²).

Outcome measures: A three-dimensional back scan was performed to measure the upper back posture in habitual standing. The tolerance ranges and confidence interval were calculated. Group differences were tested by the Wilcoxon-Mann-Whitney-U-test.

Results: In normal posture the spinal column was marginally twisted to the left and the vertebrae were marginally rotated to the right. The kyphosis angle is larger than the lumbar angle. Consequently, a more kyphotic posture is observed in the sagittal plane. The habitual posture is slightly scoliotic with a rotational component (scapular depression right, right scapula marginally more dorsally, high state of pelvic right, iliac right further rotated anteriorly).

Conclusions: Healthy young women have an almost ideally balanced posture with minimal ventral body inclination and a marginal scoliotic deviation. Compared to young males, women show only marginal differences in the upper body posture. These values allow a comparison to other studies, both for control and patient data, and may serve as guideline in both clinical practice and scientific studies.

Key words: body posture, back scan, standard value, female subjects

Strengths and limitations of this study

- Strength: large number of healthy young female participants aged 21-30 years.
- Strength: Videoraster-stereografic quantitative analysis of the upper back posture.
- Limitation: measurement of the upper body posture only in habitual standing position, not while moving.
- Limitation: external influences (occupational environment) were not assessed which might influence the body posture.

Introduction

Various subjective and objective methods to quantify and analyze the body posture have been used, especially for the spinal posture. All prior methods tried to evaluate deformity in the diagnosis and treatment of spinal diseases like scoliosis [1-4].

Quantitative analytical methods enable the diagnosis of spinal curvature deviations and/or control the therapeutic effects. The methods vary by their technical complexity and clinical applicability. Roentgenograms or computed tomography scans are frequently used for bone structure deformities, while ultrasound, inclinometer, thermal infared imaging, scoliometer or video raster stereography are established postural measurement methods [5-10]. X-ray based methods despite their mutagenic potential still are the gold standard in diagnosis and follow-up of body posture deviations [11-14].

Video raster stereography has recently been evaluated as an alternative method to quantify vertebral column posture and its deformities [7 8 15-18]. Guidelines for orthopedic rehabilitation in Germany also recommend a follow-up check but do not specify the methods [19]. The three-dimensional back scan measures the body geometry between the 7th cervical vertebrum and the gluteal cleft, it has high intraclass correlation coefficients and good Cronbach's Alpha values for intra- and interday reliability for all spine parameters [17 18 20 21]. Furthermore, inter tester reliability is high [17].

A three-dimensional surface contour image of the back appears suitable to determine vertebral column deformities, but also to quantify the effect of e.g. orthopedic shoe insoles on the body posture [22 23]. In addition, 3D images can quantify muscular imbalances (kyphotic / lordotic deviations, differences in waist contours, rotation in the shoulder or pelvis) and control the therapeutic success of muscle training in primary, secondary and tertiary prevention [24 25].

Due to the changing workplace environment with its increase in digital work, ever more employees work in a sitting position. Both in the workplace and in the household, this leads to a steady decrease of physical stress on the body. This lack of exercise may result in the development of muscular imbalances and increasing numbers of persons with back pain, currently estimated at 20 million people for Germany [20] . Back pain complaints due to musculoskeletal disorders can lead to disability or early retirement. Even more frequently, rehabilitation is required to restore the capacity to work in their original occupation.

Early signs of postural disorder e.g. musculoskeletal imbalances should be detected when subjective symptoms have developed, and treated appropriately; in order to assess both diagnosis and treatment effects, quantitative classification criteria are necessary for deviations from normal posture. These deviations should be quantified, e.g. in the form of (parametric or non-parametric) percentiles, similar to the Z- or T-scores of bone density [26]. However, no standard or reference values for body posture currently are published for healthy female subjects; reference values of the upper body posture for healthy men have been published only recently [27]. Also, classifications of the severity of posture deviations are only possible when deviations from standard or reference values are quantified.

This study measures the upper body posture in healthy women aged 21 - 30 years by a three dimensional back scan to provide standard values for the posture of young healthy women. These values and their variances define the normal upper body posture and its variability and may be used to categorize the results of other (orthopaedic) studies. Investigating a homogeneous group of subjects eliminate constitutional, habitual and degenerative changes that could increase both tolerance ranges and confidence intervals [28-31].

Methods

Subjects and Public Involvement

106 female volunteers between 21 and 30 years (25.1 ± 2.7 years) participated in this study. Their body weight ranged from 46-106 kg (60.3 ± 7.9 kg), the height from 1.53 to 1.82 m (1.69 ± 0.06 m), and the body mass index ranged from 16.9 kg/m² to 37.6 kg/m² (21.1 ± 2.6 kg/m²). 6% of the participants were underweight (BMI < 18.5 kg/m^2), 87.8% of the participants had a normal BMI (18.5 to 24.9 kg/m²), 4.7% were overweight (BMI 25 to 29.9 kg/m²) and 0.9% had obesity I° (BMI 30 - 34.9 kg/m²) according to the WHO weight classification [32] .

All subjects were healthy and free of musculoskeletal complaints and therefore no patient were involved. Using a questionnaire temporomandibular system disorders were excluded [33] ; 95.3% of the subjects reported to be right-handed and 4.7% were left-handed. 72.6% of the participants were students, 27.4% employees in different occupations (dentists, physicians, teachers, office workers).

No patients were involved. All volunteers were healthy (no patients involved) and informed about the study design before giving written informed consent. The study was approved by the local medical ethics committee of the medical faculty (Goethe-University Frankfurt; No. 303/16).

Measurement system

A three-dimensional back scan was performed to quantify the upper back posture while standing, using the back scan system "MiniRot Kombi" (ABW GmbH, Frickenhausen/Germany).

In this system a projector forms a stripe pattern on the persons bare back; this stripe pattern is captured by a LCD camera from a defined angle. One measurement lasts approx. 2 seconds. In this way the back surface is represented as a phase picture which is analyzed by an integrated software program reconstructing the 3D image. For calibration of the phase pictures all test persons are marked at six defined, standardized anatomical locations (Fig. 1) indicating underlying bone structures. These allow the calculation of three-dimensional parameters (Fig. 1) with information about rotational movements in the shoulder and pelvic area and the shape of the spine (lordotic, kyphotic and/or scoliotic posture). Artifacts may be caused by different marker placements or movements during the scan, i.e. the projection of the stripe pattern on the back, and thus have to be avoided. To measure the body posture, three repeat measurements are taken within 2 minutes.

Fig. 1

During a movement sequence 15 photos were taken. The maximum picture frequency of the MiniRot Kombi system is more than 50 frames/sec with a spatial resolution of 1/100 mm. The calculation of the three-dimensional coordinates of the back surface is performed by triangulation. The system error is specified as <1 mm (manufacturer information), the reproducibility is limited by the calculations of the upper body posture defined by markers directly on the skin (<0.5 mm).

Body scans

The subjects stood barefoot in their habitual body and jaw posture about 90 cm in front of the back scan apparatus. The arms were hanging loosely; the subjects looked horizontally fixing the opposite wall.

Evaluation Parameter

From the three-dimensional back scan three components were quantified: spinal area (markers on C7 and L5), shoulder area (markers at the top of the left/right scapula) and pelvis area (markers on the left/right spina iliaca posterior superior [SIPS]). The marker positions are shown in Figure 1, the spine parameters are selected and calculated as described in [27].

Statistical evaluation

All calculations were carried out using BIAS (Version 11.0) (Epsilon Verlag, Darmstadt, Germany). Parameter distribution was tested by the Kolmogorov-Smirnov-Test indicating only partially normal distribution; parametrical or non-parametrical tolerance regions were calculated as defined by the upper and lower limit for 95% of all values (+-2 SD values), being found in > 95% of the examined subjects. Values within this range are considered "normal".

Furthermore, the two-sided 95% confidence interval was calculated and indicated the range of the mean or median value – depending on the distribution quality – and showed the "accuracy" of these values. For group differences, the t-test or the Wilcoxon-Mann-Whitney-U-test was used.

Results

Only the constitutional parameter "body height" was normally distributed, whereas "body weight" and "BMI" were not. The median body weight was 60 kg (tolerance range 49.0 to 77.28 kg; confidence interval 57 to 62 kg). For the BMI a median of 20.7 kg/m² was calculated, with a corresponding tolerance range from 17.99 to 27.2 kg/m² and a confidence interval from 20.3 to 21.3 kg/m². For the body height a mean value of 1.69 m was calculated with a tolerance range between 1.57 and 1.82 m and a confidence interval of 1.68 to 1.70 m.

Handedness as a relevant parameter had been refused in advance by the t-test and the Wilcoxon-Mann-Whitney-U-test. All parameters were not significantly different ($p \geq 0.05$).

From the back scan values the posture of an average healthy female person was calculated (tab. 1). On average the subjects are standing slightly inclined in the anterior line of 3.31° (tolerance range 8.12° ventrally to 1.50° dorsally; confidence range 3.78° to the left to 2.85° to the right).

Laterally, a minimal deviation of the frontal trunk of 0.43° to the left was seen, the confidence interval (0.18° right – 0.67° left) included the perpendicular position; the tolerance interval ranged from 2.91° to the left to 2.06° to the right. In compensation the axial deviation (inclination between upper body and pelvis) was slightly tilted to the right (0.21°) with a tolerance range of ±4.5° and a confidence interval of <1° (0.25° left and 0.66° right). This implied that there are no obvious differences in the inclination between the upper and lower body.

The angle of the thoracic bend was calculated from the distance between the vertebra prominens (VP) and the kyphosis apex and indicated the deviation from the perpendicular line. The median angle was 13.9° confirming the expected thoracic kyphosis. Here, wider variations were seen with a tolerance range from 6.49° to 21.31°, and a confidence interval varying from 13.19° to 14.62°. The lumbar bending angle describes the deviation of the distance between the lordosis and kyphosis apex. As compared to the thoracic bend, similar variations of the tolerance value and the confidence intervals were seen in the lumbar region, with a bending angle of 13.17° (tolerance value 7.83° to 23.06°; confidence interval 11.90° to 14.25°).

Measurement of the lateral deviation showed a right-sided inclination of the median line by 3.92° when connecting the points VP and the center of the pelvic markers. Both the tolerance range (0.50°and 7.33° respectively), as well as the confidence interval (3.59°/4.25°) indicated a right-sided deviation.

The rotation of the spinal column is a marker of the spinal column torsion and can be measured from the spinal processes. In our analysis, a negative value indicates a rotation to the left and a positive value to the right. The median rotation was 4.66°, with a tolerance range between 2.04° and 12.92°, and a confidence interval between 4.18° and 5.29°. Consequently, on average a right sided spinal rotation was found.

The kyphosis and lordosis angle have a mean or a median of 51.66° and 46.29°, with a substantial tolerance range of approximately ±25° and a confidence interval of about ±2°.

Shoulder parameters are valid indicators for upper body posture (tab. 1), too. The lower scapular spinae were measured by fixed markers; the interscapular distance as indicator of the variability of the upper body was 150.56 mm, with a tolerance range of 110.51 – 190.60 mm, and a confidence limit of 146.68 – 154.43 mm. The scapular height (deviation from the horizontal line) refers to a slightly lower left shoulder blade (by 1.28°), whereas the upper and lower limit of the range markers were -22.36° and 19.81°, so that the left shoulder blade is more caudally in the lower limit and more cranially in the upper limit. The same variation is shown by the data of the confidence interval, with values of -3.32 (left scapula higher) – 0.76 ° (right scapula higher).

The shoulder markers illustrated a right shoulder being slightly further dorsal by 3.06°, with a tolerance range of -3.26° to 9.37° and a confidence interval of 2.44° to 3.67°. Only minor differences were seen between the left and right shoulder blade angles, with the right shoulder 2.6° (median) more caudally.

Table 1 also compiles the pelvic parameters. The distance for the spina iliaca posterior superior markers refers to the pelvic width, which on average is 99.56 mm (tolerance range 74.76 to 122.37 mm, confidence interval 97.17 and 101.96 mm).

The deviation of the pelvic height (in degrees) from the horizontal plane is very low. Both differences in pelvic height (in mm) and deviations from the horizontal line (in degrees) indicate a slightly higher position of the right pelvis by approx. 1° or 1 mm (Tab. 4). The same applies to the pelvic torsion and rotation, so that the right iliac marker is rotated posteriorly and simultaneously tilted further ventral (mean pelvis torsion: 0.24 °; mean pelvic rotation: 2.2°).

Tab. 1

Discussion

This paper presents normal values and normal ranges including tolerance and confidence intervals for the body posture of healthy young females. Height, weight and body mass index (BMI) of the participants are comparable to average young German female persons [34 35]. as measured by Mensink et al. [34] in over 7000 adults from the general German population. The age-matched female group from Mensink et al. [34] was 3.20 cm smaller, 4.92 kg heavier and thus also had a slightly higher BMI by 2.58 kg/m² as compared to our values. Similar findings have been reported by the German Federal Statistical Office in 2011 for 2009 [35], which correlate even better to our results.[34]. Data for height, weight and BMI, obtained to assess the prevalence of obesity in Germany between 1985 and 2002 [36] in 1504 female volunteers (25-29 years) show that the subjects in our study are marginal taller, lighter and have a lower BMI.

In this context, however, it should be borne in mind that this study mainly involved students and university employees with the same lifestyle, with values slightly differing from the general population, and a likely overrepresentation of participants with a high social status.

87.8% of the participants in this study have a normal BMI, 22.3% more than Mensink et al. [34] found for 18-29 year old women. The relation of overweight with social status is well known; this confounder is also seen by the data from Mensink et al. [34] ; 36.9% of women with a low social status were overweight, 16.4% obese as compared to 18.7% overweight and 4.4% obese women with a high social status. Helmert et al. [36] calculated similar data using the equivalent household income; thus the different BMI values likely are explained by the participant selection preferentially from the students of the School of Dentistry in our university, with a high social status.

The back scan values indicate a characteristic posture of young females. Only small deviations from an ideal perpendicular position are noted; the ventral tilt of the trunk, the lateral deviation and rotation of the spine, shoulder and pelvis were very small. The posture is marginally scoliotic (the ventral trunk tilts marginally to the left side, the scapula is higher on the left side, the pelvis slightly elevated on the right side) with an expected rotatory component (a lumbar right tilt to compensate for the left tilted ventral trunk, a slight twist of the processus spinosus to the right, the right scapula marginally more dorsal, the SIPS of the right iliac bone rotated anteriorly) (Tab. 1). The spinal curve, defined by the thoracic and lumbar bending angle and the kyphosis and lordosis angle, indicates that the angle in the thoracic spine area is marginally larger than that in the lumbar region (Tab. 1), and a slightly kyphotic posture in the sagittal plane can be observed.

Handedness has no influence on these parameters, which should be expected from the observed symmetry. However, since 95.3% of the participants were right-handed no firm conclusions can be drawn for left handed people. Also, whether an influence of the dominant leg [37] exists on the posture cannot be answered by our results. Appropriate test methods for the determination of these components should be used in further studies.

A gender comparison [27] shows only marginal differences in the upper body posture. Both studies used the same measurement system and data evaluation and thus allow a direct comparison of the values. Although the female upper body appears narrower and more delicate due to the weaker muscular shoulder girdle and the smaller chest, the ratio between chest and shoulder width is the same [38].

The anatomical and constitutional differences are confirmed by the present data. In terms of the shoulder width, the fixed scapular landmarks indicate a larger distance of 2.9 cm in men than in women (Table 1). In contrast, men have a smaller pelvis calculated from the SIPS markers (6 mm difference) which results in a wider shoulder than pelvis distance by 8.5 cm in men, but only 5.0 cm in women, confirming and quantifying the well-known gender-specific anatomical differences.

In addition to these constitutional differences, differences in the lordotic and kyphotic angles are calculated from the spinal column parameters. Thus, women have an average kyphotic angle of 52°, men of 46°; the lordosis angle is 46° for women and 31° for men. Thus, the spinal curvature in the thoracic and lumbar spine area is more pronounced in women than in men. The difference in the lordosis angle between the sexes is about 15° and in the case of the kyphotic angle with approximately 6°, however, men have an approximately 15° greater thoracic kyphosis angle than lumbar lordosis angle in contrast to a 6° difference of women. Consequently, the kyphosis angle is larger than the lordosis angle in both sexes, women are in a more balanced posture due to the smaller difference between the two angles.

Liu et al. [39] tried to define standard parameters of cervical spine alignment and range of motion related to age, sex, and cervical disc. These results underline the more pronounced thoracal kyphosis in women. The greater lumbar lordosis of the females can be traced back to sex differences in the pelvic shape: The wider pelvic blades of the female pelvis have a larger angle between the pubic branches, a larger transverse pelvic diameter and are lower. Thus, the pronounced female pelvic tilt leads to a larger lumbar lordosis. Consequently, a larger lumbar lordosis causes a thoracal hyperkyphosis. These (different) compensations are seen in the pelvic position in both sexes [38]. This position of the lumbar spine also affects the extent of the movement in the flexion-extension testing of the trunk. The total task-specific hip motion ranges as measured from erect standing to the maximum flection were higher in females than in males [40].

Furthermore, the same authors report that female chronic low back pain patients had higher regional hip and trunk motion ranges than male patients [41]. Why women have a larger lordosis angle currently is unknown. An extensive literature search in PubMED and other data bases did not retrieve any published hypothesis. An explanation of physiological differences, however, has been forwarded to comparable sex differences in the pelvic anatomy for rodents and has been related to sexual behavior in these animals. Guinea pigs show hormonally controlled, gender related reproductive behaviour: male guinea pigs show a distinct sexual approach consisting of body raising, intromission and ejaculation, and female guinea pigs respond with a corresponding conceiving position of a predominantly lordotic lumbar posture [42 43]. At least for this species the observed anatomical differences may translate directly into an apt reproductive behaviour. In both species, the pelvis itself has the same position in both sexes in a relaxed posture, and is positioned almost horizontally.

No similar explanation exists for differences in the shoulder region parameters either; the right shoulder is positioned more caudal in both sexes, but women have “deeper” shoulders (increased scapular angle right/left).

All other positional parameters are nearly identical between men and women, with the differences being smaller than the margin of error, and likely have no clinical relevance.

The three-dimensional back scan is a fast, non-contact method to quantify the body posture and is suitable for measuring body postures in both healthy persons and patients. It can quantify pathologic positions like scoliosis, kyphosis, leg length differences and functional movement disorders, as well as improvements by medical treatment. The chances and limitations of the measurement system and procedure [44-50] has already been discussed by Ohlendorf et al. [27 51]. In the future, this method may allow to grade postural deviations, e.g. by a grading system using the tolerance ranges for men and women, as has been done for bone densitometry in the t- and z-scales [26].

Conclusion

Video raster stereography is a method to quantitatively measure the human three-dimensional back surface. Healthy young women have an almost ideally balanced posture with minimal ventral body inclination and a marginal scoliotic deviation. In comparison to men women have only small differences in upper body posture, with nearly identical normal values. These values allow a quantitative comparison with other studies for control and patient data, and may serve as an orientation in both clinical practice and scientific studies. Further studies could expand this method to age-related changes in body posture, quantitative assessments of postural changes in relevant diseases, and improvements by therapeutic interventions.

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a. contributorship statement

DO, VF, CD, SS, GO and JS made substantial contributions to the conception and design of the manuscript, DO, VF and CD made substantial contributions to the construction of the measurement protocol and HA and DO have been involved in the statistical data analysis. All authors have read and approved the final manuscript.

b. competing interests

The authors declare that they have no conflict of interest.

c. funding

There is no external funding of the project.

d. data sharing statement

No additional data available.

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Tables

Tab. 1 Spine, shoulder and pelvis parameter: mean value, median, tolerance regions (upper and lower limit), confidence interval (left and right limit). Italic data are non-parametrical values.

	Mean value/ median	tolerance range lower limit	tolerance range upper limit	confidence interval left limit	confidence interval right limit
Spine parameter					
Trunk length D (mm)	461.31	412.95	509.67	456.64	465.99
Trunk length S (mm)	509.52	458.88	560.15	504.62	514.41
Sagittal trunk decline (°)	-3.31	-8.12	1.5	-3.78	-2.85
Frontal trunk decline (°)	-0.43	-2.91	2.06	-0.67	-0.18

Axis decline (°)	0.21	-4.45	4.86	-0.25	0.66
Thoracic bending angle (°)	13.9	6.49	21.31	13.19	14.62
Lumbar bending angle (°)	*13.17*	*7.83*	*23.06*	*11.9*	*14.25*
Standard deviation lateral deviation (mm)	3.92	0.5	7.33	3.59	4.25
Maximal lateral deviation (mm)	*-5.35*	*-12.8*	*12.38*	*-5.76*	*-0.89*
Standard deviation rotation (°)	*4.66*	*2.04*	*12.92*	*4.18*	*5.29*
Maximal rotation (°)	*9.2*	*-9*	*37.48*	*8*	*10.76*
Kyphosis angle (°)	51.66	27.91	74.42	49.37	53.96
Lordosis angle (°)	46.29	21.66	70.92	43.91	48.67
Shoulder parameter					
Scapular distance (mm)	150.56	110.51	190.6	146.68	154.43
Scapular height (°)	-1.28	-22.36	19.81	-3.32	0.76
Scapular rotation (°)	3.06	-3.26	9.37	2.44	3.67
Scapular angle left (°)	28.54	16.49	62.74	27.36	30.74
Scapula angle right (°)	31.17	10.61	73	27.2	34.62
Pelvis parameter					
Pelvis distance (mm)	99.56	74.76	124.37	97.17	101.96
Pelvis height (°)	0.76	-4.29	5.81	0.28	1.25
Pelvis height (mm)	1.34	-7.33	10.01	0.5	2.18
Pelvis torsion (°)	0.24	-6.89	7.36	-0.45	0.93
Pelvis rotation (°)	2.2	-5.72	7.34	1.49	2.76

Figure legend

Fig. 1: a) back scanner MiniRot Combi (ABW GmbH, Frickenhausen / Germany), b) three-dimensional phase picture of the back c) marker position on the back: A: Vertebra prominens (7th cervical vertebra), B: Lower scapular angle left, C : Lower Lower scapular angle right, D: Spina Iliaca Posterior Superior (SIPS) left , e: Spina Iliaca Posterior Superior (SIPS) right, F: Sacrum-point (cranial beginning of the gluteal cleft).

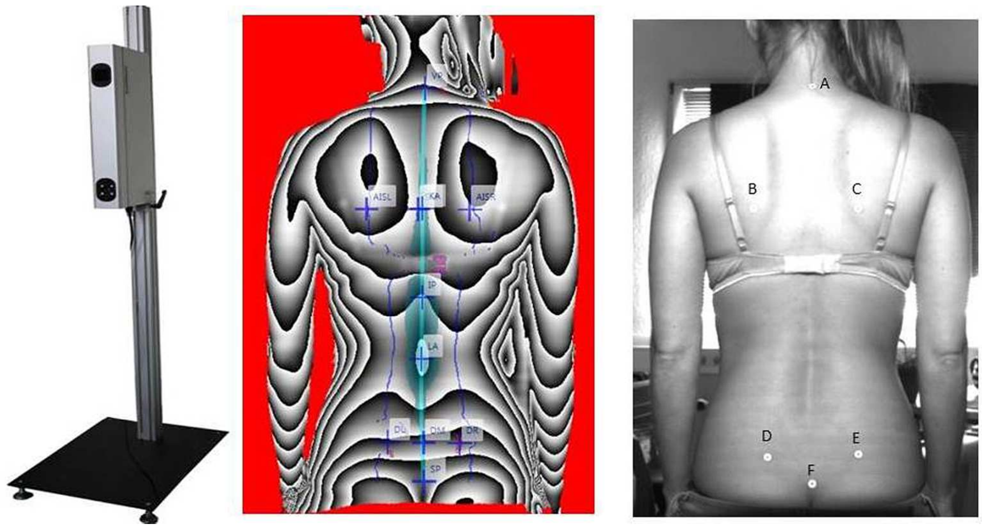

Fig. 1: a) back scanner MiniRot Combi (ABW GmbH, Frickenhausen / Germany), b) three-dimensional phase picture of the back c) marker position on the back: A: Vertebra prominens (7th cervical vertebra), B: Lower scapular angle left, C : Lower Lower scapular angle right, D: Spina Iliaca Posterior Superior (SIPS) left , e: Spina Iliaca Posterior Superior (SIPS) right, F: Sacrum-point (cranial beginning of the gluteal cleft).

199x103mm (300 x 300 DPI)

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Pages
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	4,6-8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-8
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	6
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	n/a
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-8
Bias	9	Describe any efforts to address potential sources of bias	n/a
Study size	10	Explain how the study size was arrived at	6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8
		(*b*) Describe any methods used to examine subgroups and interactions	n/a
		(*c*) Explain how missing data were addressed	n/a
		(*d*) If applicable, explain how loss to follow-up was addressed	n/a
		(*e*) Describe any sensitivity analyses	n/a
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	n/a
		(b) Give reasons for non-participation at each stage	n/a
		(c) Consider use of a flow diagram	n/a
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8-9
		(b) Indicate number of participants with missing data for each variable of interest	n/a
		(c) Summarise follow-up time (eg, average and total amount)	n/a
Outcome data	15*	Report numbers of outcome events or summary measures over time	9-11
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9-11
		(*b*) Report category boundaries when continuous variables were categorized	9-11
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9
Discussion			
Key results	18	Summarise key results with reference to study objectives	11-15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of	11-14

		analyses, results from similar studies, and other relevant evidence	
Generalisability	21	Discuss the generalisability (external validity) of the study results	14-15
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	2

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

n/a = not applicable

Since the study investigated healthy young women in an observational study these parts of the STROBE-criteria are not applicable.