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Measurement of Spinal Sagittal Curvatures using the Laser Triangulation Method

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A B S T R A C T

The purpose of the first part of the study was to establish the variability of repeated measurements in different measuring conditions. In the second part, we performed in a large number of patients, a measurement of thoracic kyphosis and lumbar lordosis and compared them to age, gender, and level of nourishment. In the first part, measurements were performed on a plastic model of the back of a patient with a rigid and a normal spine. In the second part, 250 patients participated in the study (126 men and 124 women). For measuring spinal curvatures we used an apparatus for laser triangulation constructed at the Faculty of Mechanical Engineering, University of Ljubljana. A comparison of 30 repeated measurements was shown as the average value±2 SD which included 95% of the results. Thirty repeated readings of one 3D measurement: thoracic kyphosis 41.2°±0.6°, lumbar lordosis 4.4°±1.2°; 30 measurements on a plastic model: thoracic kyphosis 36.8°±1.2°, lumbar lordosis 30.9°±2.0°; 30 measurements on a patient with a rigid spine: thoracic kyphosis 41.5°±2.4°, lumbar lordosis 4.0°±1.8°; 30 measurements on a patient with a normal spine: thoracic kyphosis 48.8°±7.4°, lumbar lordosis 21.1°±4.4°. The average size of thoracic kyphosis in 250 patients was 46.8° (SD 10.1°) and lumbar lordosis 31.7° (SD 12.5°). The angle size was statistically significantly correlated to gender (increased thoracic kyphosis and lumbar lordosis in women) and body mass index (increased thoracic kyphosis and lumbar lordosis in more nourished patients). Age was not significantly correlated to the observed angles. During measurements of the spinal angles it was important to pay attention to relaxation and the patient's position as well as to perform more measurements providing the average value. The age and the level of nourishment influence the size of the sagittal spinal angles. In the observed sample the effect of age was not confirmed.

Key words: *spine curvature, thoracic kyphosis, lumbar lordosis, measurement, laser triangulation*

Introduction

An analysis of the upright posture of a human is important, since a deviation from the correct posture can cause problems or indicate a presence of a pathological appearance. For the determination of a correct body posture it is necessary to determine the spinal sagittal curvatures. In this case, we can add various measurement techniques to the clinical assessment. According to the spine anatomy, the most precise method is the side RTG snapshot and measurement of the curvature's alignment in part of the vertebral bodies[1]. The measured angle is in literature mostly referred to as the Cobb's angle; however, this name is in detail also intended to describe the scoliosis angle, measured in the front plane. As an exception, the correct description – »Q« angle has also been appearing, which presents the curvature in the sagittal curvature. The reading of the angle can be carried out manually or automatically in a digitalised picture; both methods are accurate and match each other[2]. The problem of the side RTG snapshot, which is being implemented for the determination of sagittal curvatures, is the overlapping of the shoulder ring shade with the upper part of the thoracic spine. Therefore, the upper limit of the curvature is largely read at the Th_4 level; however, in this way the angle of the entire thoracic spine is not

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measured. The RTG method also endangers a patient with dangerous radiation which can cause cancerous diseases[3,4]. Therefore, the measurement in clinical praxis is frequently being carried out by a harmless method on the body surface.

For this purpose, various other systems, most frequently mechanical, are being implemented in clinical work and research. De Brunner's Kyphometer[2,5] is a mechanical protractor that enables the laying of an individual arm to two adjacent spinous processes, which therefore provides a stable position when reading. The Flexicurve ruler[5,6] is a plastic device, which adjusts itself to the back curvature. A gravitational goniometer enables a direct measurement with a rest of the apparatus fixed on the back and a reading of the indicated angle according to the vertical. If at one point we set the angle to 0°, the other point shall immediately indicate the angle of the measured curvature. A similar device is Myrin's inclinometer[7], which also enables measurements in the horizontal plane with the aid of a compass. In literature, we can also find the use of a curviscope[8]. This is an electronic measurement device, which detects mutual positions of individual units and provides a value of the measured curvature by using potentiometers which are positioned along the spine. Another used method is an ultrasound measurement of the position of the sensors, which are located in random points of the body area[9].

The validity, reliability and repeatability of such measurements are different. Partly they depend on the experience of the investigator and the accuracy when setting the measurement device to the skin. A measurement of the back surface naturally provides slightly different results than a direct RTG measurement of the spine; however, the differences are insignificant, and in literature we can find formulas for the calculation of the Cobb angle from the surface measurement value[10].

An ideal solution is provided by the methods of non-contact measurement in the form of a snapshot of the surface, which is illuminated by various sources of light[11]. One of such methods is laser triangulation, which has been implemented for various measurement purposes in medicine for a number of years[12–14]. The laser beam energy needed for this kind of measurement is so low that direct eye exposure is completely harmless[11]. The most recent articles deal with scoliosis detection using the laser triangulation method and calculation of torso asymmetries[15–17]. The reliability of measuring the patient's 3D back shapes has not been documented. The articles rarely report of data on the patient's posture and the number of measurements performed on an individual. Measurements of spine curvatures were being implemented using a number of different methods. A researcher from 1986 published the sizes of the thoracic kyphosis angle and lumbar lordosis angle, which were measured by the Myrin's inclinometer[18]. A survey of expert publications does not provide any data on the measurement of spine curvatures using the method of laser triangulation in a larger group of healthy subjects.

The purpose of the study is to establish the variability of repeated measurements in different measuring conditions. Measuring thoracic kyphosis and lumbar lordosis and comparing to age, gender and level of nutrition was performed on a larger number of patients.

Patients and Methods

The research incorporated 250 subjects, who had otherwise sought help in the clinic due to other problems, reasons that were not connected with the spine. They were also incorporated in random order, as they appeared in the clinic.

The subjects had to meet the following inclusion criteria:

- persons of male or female gender with the age between 20 and 70 years,
- clinically determined »normal« spine curvature without present deformation of the back,
- horizontal position of the pelvis in standing position,
- ability to stand calmly relaxed,
- willingness of the subject for their cooperation.

Criteria for exclusion were also set:

- anamnesis of a back injury due to fracture,
- anamnesis of pain in the spinal area during the last year,
- spine operation,
- clinically detected or RTG visible scoliosis.

The working methods were presented to the subjects, who were asked for their voluntary participation in the research. The anonymity of the subjects was guaranteed. The gender, age and basic anthropometric measurements: body height and weight were indicated. On the back of a subject, short horizontal markers were drawn by a felt pen in the areas of the transition spine zones: cervico-thoracic transition between the spinous process C_7-Th_1, thoraco-lumbar transition Th_{12}-L_1 and lumbo-sacral transition L_5-S_1. The marker positions were determined with the palpation of the spinous processes. When determining the level of the thoraco-lumbar transition, the position of the twelfth rib was also of great help. The orientation line for the lumbo-sacral level was the height of the iliac crests, which run across the procesus spinosus L_4.

Three-dimensional measurements of the back were carried out using a laser triangulation measurement system[19], see Figure 1-a. It operates on the active triangulation principle[20]. Figure 1-b depicts this measurement principle: a laser projector (670nm, 5mW) »1«, emits a light plane »2«, and illuminates the surface of the back »3«. The bright line »4« that is visible on the surface (red profile) is acquired by the camera »5«. The result of one measurement is a profile »4« (having 640 points) representing a cross-section of the light plane and the illuminated surface of the back »3«. In order to measure the complete spine, the surface of the back is scanned – the

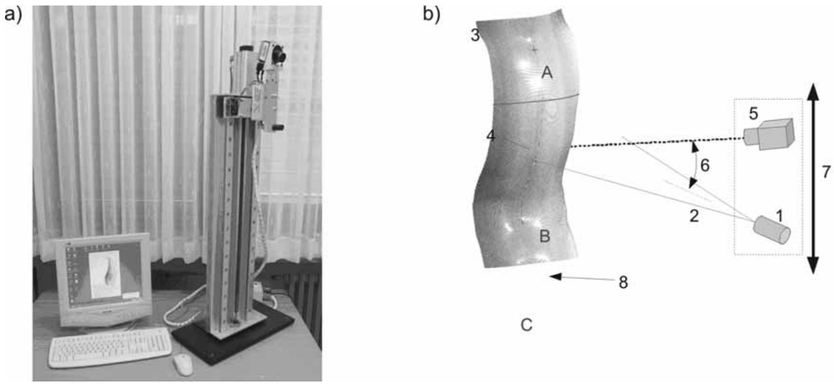

Fig. 1. (a) A laser triangulation measurement system; (b) The triangulation measurement principle.

measurement system is translated »7« in a direction perpendicular to the spine by using a translation stage. The profile measurement process operates at a frequency of 80 profiles *per* second. The translation system takes about 10 sec to move the measurement system across the scan length of 700 mm. The smallest distance between the measured profiles (scanning resolution) thus depends on the translation speed and measurement frequency and is ~0.87 mm. The whole measuring volume thus depends on the camera optics and translation length and is 300×700×500 mm (width×height×depth). The single point measurement accuracy is 0.1 mm.

A three-dimensional measurement is analysed in a way that the spine shape is calculated first (see Fig. 2a, red line). For that purpose the maximum/minimum value of the convex/concave shape formed by a spine ridge is detected in profiles where the spine ridge is visible. Otherwise path connecting markers are used to calculate the spine shape. Figure 2b shows the spine shape in the sagittal plane as is determined from the measurement. In the marker positions, straight lines are fitted to the curve showing the spine shape. The angles of interest are calculated between these lines. The shortest and the arc distance between the markers are also calculated.

The accuracy of determining the spine shape from the measurements was verified by a reference method – the mechanical tactile coordinate device DEA Iota Diamond Model 01.02, having certified measurement accuracy better than 5 μm, see Figure 3. Both methods were employed to measure the sagittal spine shape of a plastic model designed according to the back's shape. The difference between the two methods was less than 0.3 mm, see Figure 4.

Fig. 3. A mechanical tactile coordinate device, DEA Iota Diamond measures a plastic model.

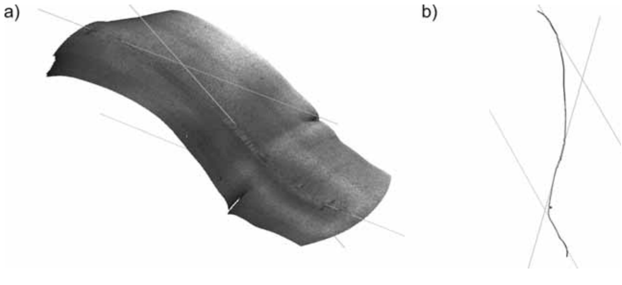

Fig. 2. a) An example of three-dimensional measurement of the back and its analysis. The red line shows the spine shape as is calculated from the measurement. Three marker points are visi-

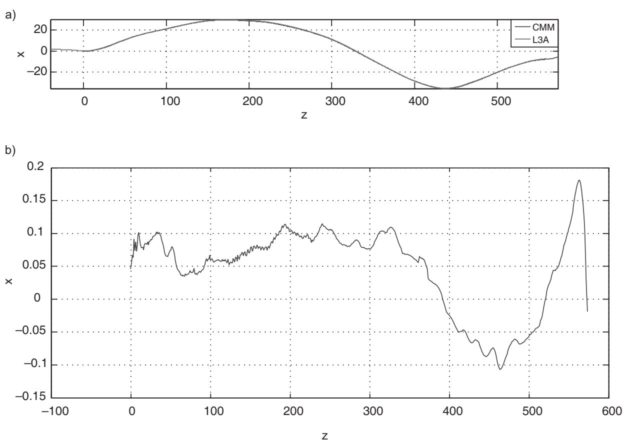

Fig. 4. a) A shape of a spine in the sagittal plane measured on a plastic model. Blue line: reference measuring system (CMM); Red line: shape determined from the laser triangulation measurement (L3A). b) Difference between the measurements.

In the first part of the study, the spinal curvatures were defined in four measuring scenarios:

1. On a randomly chosen measurement of the back in one of the patients, 30 successive readings of thoracic kyphosis and lumbar lordosis angles were performed. The purpose was to check the result variability occurring due to small differences in each position of the reading spot. The patient sets the spot by clicking in the middle of the cross marking a transient spinal zone.
2. The effect of the patient's position regarding the measuring system was verified by means of a plastic model ensuring a completely rigid "back" where the same spots were marked as in live subjects. During each of 30 measurements, the position of the plastic model was somewhat changed in all three surfaces imitating different postures of patients.
3. The measurement was repeated 30 times on a subject who had on account of disease, distinctively decreased thoracic and lumbar mobility. The purpose was to check the result variability in repeated measurements in a patient with poor spinal mobility.
4. Lastly, we verified the variability of the obtained results in normal conditions on a subject with physiological spinal mobility who has occupied a measuring position 30 times. For that reason the subject moved around the room after each measurement.

In the second part, the measurement of thoracic kyphosis and lumbar lordosis was performed in 250 subjects. Each one was measured three times; the average was calculated to improve the accuracy and to minimise the effect of patient movement.

The study was approved by the Ethics Committee of the University Clinical Centre Maribor.

Statistical analysis

The basic descriptive statistic was carried out using the program Excel (MS Office). A comparison of the average from the two data groups was performed with a t-test after the normal data distribution inside each group was confirmed by the Kolmogorov-Smirnov test. The matching of the two data groups was also verified by the Pearson linear correlation test. The correlation between the observed parameters was verified with the linear regression test. For these calculations, the software SPSS 12.0.1 for Windows was implemented.

Results

The first part of the study was conducted in the form of 30 repeated measurements in four testing conditions – the results are shown in Table 1. The results display an increasing variability of the repeated measurements. If we take into account that 95% of the results that are in a normal distribution of data were within the average±2 standard deviation, the results are the following: – the lowest variability in the repeated reading of a single 3D measurement (ThK±0.6°, LuL±1.2°), slightly increased the variability in the measurement performed on the rigid plastic model (ThK±1.2°, LuL±2.0°), and slightly increased in the measurement performed on a live subject with a rigid spine (ThK±2.4°, LuL±1.8°). The largest variability of results was displayed by the repeated measurements on a subject with a normal spine (ThK±7.4°, LuL±4.4°).

TABLE 1
AVERAGE VALUE AND STANDARD DEVIATION OF 30 REPEATED MEASUREMENTS OF THORACIC KYPHOSIS AND LUMBAR LORDOSIS IN FOUR TEST SCENARIOS

Measuring method	Thoracic kyphosis (°)		Lumbar lordosis (°)	
	Average	St.dev.	Average	St.dev.
One picture	41.2	0.3	4.4	0.6
Plastic model	36.8	0.6	30.9	1.0
Rigid spine	41.5	1.2	4.0	0.9
Normal spine	48.8	3.7	21.1	2.2

One Picture – repeated reading of one measurement
Plastic Model – measurements on a plastic model
Rigid Spine – measurements on a subject with a rigid spine
Normal Spine – measurements on a subject with a normal spine.

In the second part, 250 subjects participated in the research, of which 126 (50.4%) were men and 124 (49.6%) women. The average age was 42.2 (st.dev. 12.2, from 20 to 69) years without significant differences between the sexes (t-test: $p>0.05$). The average body mass index was 26.1kg/m^2 (st.dev. 4.4, from 17.2 to 44.3).

Table 2 presents in detail the results of the angle measurements of thoracic kyphosis in all subjects as well as separately for men and women. The average value of the three angle measurements amounts to 46.8°. The results have indicated statistically significantly higher angle sizes of thoracic kyphosis in female subjects ($p<0.01$).

A similar observation is also indicated in Table 3 for the lumbar lordosis angle. The average value in all subjects amounted on average to 31.7°, while the difference was even higher and statistically more important with higher values in female subjects ($p<0.01$).

In further analysis, all subjects were subdivided according to their age into two groups:

- a younger group with ages from 20 to 45 years incorporated 150 (60%) subjects
- an older group with ages from 46 to 70 years incorporated 100 (40%) subjects.

TABLE 2
THORACIC KYPHOSIS (THK) ANGLE IN ALL SUBJECTS AND IN MEN AND WOMEN SEPARATELY

Angle (°)	ThK (all)	ThK (men)	ThK (women)
Average	46.8	44.6	49.1
St.deviation	10.1	9.0	10.7
Minimum	20.6	20.6	24.9
Maximum	79.4	69.6	79.4

Comparison of means ThK(men)/ThK(women) – t-test: $p < 0.001$

The difference in average values of the observed angles was verified – Table 4 indicates the measurement results of thoracic kyphosis and lumbar lordosis. In both cases, there were no significant differences between the average angle values in both age groups.

The results of measuring thoracic kyphosis and lumbar lordosis regarding the level of nourishment are shown in Table 5. In more nourished subjects, the average size of the thoracic kyphosis and lumbar lordosis angle was statistically significantly larger (both $p<0.01$).

Table 6 shows the results of the linear regression test by Pearson between pairs of observed variables. Low values of the correlation coefficient and the statistically insignificant correlation between age and both observed angles were established. Age is in a statistically significantly positive correlation with body mass index. The BMI is statistically significantly correlated to thoracic kyphosis and lumbar lordosis; however, the correlation coefficients were low.

TABLE 3
LUMBAR LORDOSIS (LUL) ANGLE IN ALL SUBJECTS AND IN MEN AND WOMEN SEPARATELY

Angle (°)	LuL (all)	LuL (men)	LuL (women)
Average	31.7	23.6	37.7
St.deviation	12.5	8.0	12.3
Minimum	2.1	2.1	11.3
Maximum	74.9	39.5	74.9

Comparison of means LuL(men)/LuL(women) – t-test: $p < 0.001$

TABLE 4
THORACIC KYPHOSIS (THK) AND LUMBAR LORDOSIS (LUL) ANGLE IN YOUNGER (AGE FROM 20 TO 45 YEARS) AND OLDER ONES SEPARATELY (AGE FROM 46 TO 70 YEARS)

Angle (°)	ThK (20–45)	ThK (46–70)	LuL (20–45)	LuL (46–70)
Average	46.8	46.8	31.1	29.8
St.deviation	10.2	10.0	12.4	12.6
Minimum	20.6	24.9	2.1	7.8
Maximum	79.4	75.1	73.3	74.9

Comparison of means ThK(younger)/ThK(older) – t-test: $p = 0.961$
Comparison of means LuL(younger)/LuL(older) – t-test: $p = 0.441$

TABLE 5
THORACIC KYPHOSIS (THK) AND LUMBAR LORDOSIS (LUL) ANGLE IN BMI 25 KG/M^2 (AND LESS) AND MORE NOURISHED ONES SEPARATELY (BMI MORE THAN 25 KG/M^2)

Angle (°)	ThK (25 less)	ThK (25 more)	LuL (25 less)	LuL (25 more)
Average	46.0	52.7	34.8	40.8
St.deviation	8.5	11.9	10.0	14.0
Minimum	26.1	24.8	14.7	11.3
Maximum	64.6	79.4	60.3	74.9

Comparison of means ThK(less nourished)/ThK(more nourished) – t-test: $p = 0.001$
Comparison of means LuL(less nourished)/LuL(more nourished) – t-test: $p = 0.008$

TABLE 6
LINEAR CORRELATION BETWEEN CHOSEN PAIRS OF RESULTS

Linear correlation	r	p
Age/Thoracic Kyphosis	0.06	0.330
Age/Lumbar Lordosis	–0.03	0.596
Age/Body Mass Index	0.18	0.004
Body Mass Index/Thoracic Kyphosis	0.32	< 0.001
Body Mass Index/Lumbar Lordosis	0.17	0.008
Thoracic Kyphosis/Lumbar Lordosis	0.57	< 0.001

The correlation among the observed parameters was also tested with the linear regression model. Table 7 shows the results of the dependence of thoracic kyphosis on age, gender, and body mass index and in Table 8, lumbar lordosis was the dependent variable.

The used model points to the statistically significant effect of independent variables on dependent thoracic kyphosis ($p<0.01$; $R=0.42$). The thoracic kyphosis angle in subjects is significantly dependent ($p<0.01$) on gender and the body mass index, and statistically insignificantly dependent on the subjects' age ($p>0.05$). This had already been demonstrated by previous analyses of individual variables. Linear regression additionally provides information on the extent of the effect of individual independent variables on the dependent variable. Thus the effect of the BMI on the size of the thoracic kyphosis angle was the largest and directly proportional (Beta= 0.357), the effect of gender was somewhat smaller (Beta= –0.273). The effect of age was the smallest (Beta=–0.008) and as already stated, statistically insignificant ($p>0.05$).

The linear regression also confirmed the conclusions of previously performed analyses for lumbar lordosis. It was established that the effect of age was statistically insignificant ($p>0.05$) but the effect of gender and the BMI were statistically significant. The lumbar lordosis angle was more correlated with the subject's gender (Beta=–0.604)

TABLE 7
LINEAR REGRESSION FOR ANALYSING THE DEPENDENCE OF THORACIC KYPHOSIS ANGLE ON GENDER, AGE, AND BODY MASS INDEX

Model	Non-stand. coef.	Stand. coef.	Signif.	95% Confid. interval for B	
	B	Beta	p	Lower bound	Upper bound
(Constant)	28.314		0.000	20.756	35.872
Age	–0.007	–0.008	0.890	–0.103	0.090
Sex	–5.528	–0.273	0.000	–7.865	–3.191
BMI	0.819	0.357	0.000	0.549	1.088

Dependent variable: Thoracic kyphosis

TABLE 8
LINEAR REGRESSION FOR ANALYSING THE DEPENDENCE OF THE LUMBAR LORDOSIS ANGLE ON GENDER, AGE, AND BODY MASS INDEX

Model	Non-stand. coef.	Stand. coef.	Signif.	95% Confid. interval for B	
	B	Beta	p	Lower bound	Upper bound
(Constant)	21.921		0.000	13.898	29.944
AGE	–0.098	–0.096	0.060	–0.201	0.004
SEX	–15.090	–0.604	0.000	–17.571	–12.609
BMI	0.775	0.273	0.000	0.488	1.061

Dependent variable: Lumbar lordosis

than with his/her body mass index (Beta=0.273). The correlation between age and the lumbar lordosis angle was to some extent inversely proportional (Beta=–0.096), but not statistically significant.

Discussion and Conclusion

To test the variability of the results acquired by the measuring technique used, the repeatability of the sagittal angle determination was analysed. For that purpose a rigid plastic model of the back was measured in different positions and orientations with respect to the measuring system. In the first case, 30 repetitions of the measurement showed a small variability in the result. In the average value of the thoracic kyphosis angle 41.2%, 95% of the results were within the average±0.6° and the largest absolute difference was also 0.6°. The results of measuring the lumbar lordosis showed the average value of 4.4% with a deviation of ±1.2° in 95% of the results. In measurements on the plastic model, the variability of the results was somewhat bigger. The results of measuring the thoracic kyphosis were the following: the average measured angle was 36.8°; 95 % of measurements showed a deviation ±1.2° from the average. The average value of lumbar lordosis angle was 30.9°. 95% of the performed measurements were within the range ±2° from the average. The stated values of the result variability can be considered as a »measuring error« due to the measuring technique itself. Discussion with the results of the analysis showing only the error of the laser triangulation measuring method is not possible, as in the reviewed literature such analyses were not to be found.

The variability of the measurements on a live subject was verified under two recording conditions. Measurement on a subject with a rigid spine has shown thoracic kyphosis with the average value of 41.5° with the variability in 95% of the results within ±2.4° from the average. In repeated measurements of the lumbar lordosis angle the results were the following: average value 4.0°, 95% of the results within the average ±1.8°. Repeated measurements of the subject with a normal spine, who moved around the room during individual measurements, showed the following results: the average angle size for thoracic kyphosis was 48.8°, 95% of measurements were within the average ±7.4°; the average value for lumbar lordosis was 21.1°, 95% of measurements were within the average ±4.4°. The results obtained in the subject with a rigid spine did not significantly deviate in comparison to the measurements on the rigid plastic model, which indicates that most of the variability of the results in the measurements of subjects with a normal spine can be attributed to the possibility of different spinal positions during individual measurements.

Literature data also warns of the possible error of measuring lumbar lordosis up to 10°[23]. When measuring thoracic kyphosis with an electric curviscope in 24 subjects, the author's reports of variation coefficients of 2.8% which would in the case of the angle size 50°, amount to 1.4°[6]. Comments on the occurrence of variability and data on the measuring position or subject fixation are usually not present. The literature provides formulas for calculating the RTG Cobb's thoracic kyphosis angle from the value of the surface measurement; however, data on a possible change of the subject's position during the three measurements is not included[5].

The variability of the measurements results from different spinal positions of the subject during repeated measurements. There are two possibilities of dealing with the problem: subject fixation during measurement or multiple repetitions of the measurement and calculating the average value. Studies have included both possibilities. When measuring the entire body with 4 laser systems, the authors used a measuring cell where the subject was standing. The measurement was repeated twice, but the differences in measurements were not reported in the presentation of the results[17]. Similarly, during the measurement of the entire trunk with 4 fixed laser systems on the band, a group of authors positioned the subject in a measuring cell with three fixation spots and an armrest. The measurement was performed in a standing position[24]. The authors used a large number of measurements for measuring sagittal spinal curvatures with the DeBrunner's Kyphometer. The measurements were repeated four times, insignificant differences with »r«> 0.91 were presented, however, the measurements were performed consecutively without a break and the subject was in a steady standing position the entire time[25].

If the subject moves during the measurement, it can have a partial effect on the occurrence of the differences and even more on the technical irregularities when calculating the 3D measurement. A change in position and especially thoracic movement during breathing can present a serious problem and recording time becomes very important. The measuring time of the mentioned measurements of the entire body[24] and just the trunk[25] was 15 seconds. In this study, the measurement along the back lasted 12 seconds. Regarding the presentation of this information in the published papers, the Sydesco system holds the record – the laser scanner measures the trunk in only 2 seconds[26].

The second part of the research indicates the results which were measured in the group of 250 subjects without clinically present deformations and anamnestic fractures or operations on the spine. The subjects of both sexes in the age range from 20 to 70 years and an entire spectrum of anthropometric parameters of body weight, height and calculated Body Mass Index participated.

During the examination, the subjects held a relaxed upright posture. Differences between the spine angles in re-setting the measurement position were analysed with three repetitions of the measurement, during which the subjects freely moved around in the space. The analysis has indicated that an average difference between the three measurements on an individual for the thoracic kyphosis as well as lumbar lordosis was less than 2.5°. In a smaller number of subjects, this difference could amount up to 10° for both observed angles. This result is comparable with the conclusion of the authors who reported the lumbar lordosis measurement error of up to 10°[23]. The difference appeared due to a change of the body position of a subject between individual measurements. Therefore, the performed measurements of the additional subject with a rigid thoracic and lumbar spine due to advanced ankylosing spondylitis indicated much lower variations of measurements. Furthermore, an analysis of repeated angle readings of the back measurement indicated minimum differences.

In other words, the results indicate the average angles of sagittal curvatures in a relaxed upright posture of the subjects. The obtained average value of the thoracic kyphosis angle amounted to 46.6°, and the lumbar lordosis angle 30.0°. The values for thoracic kyphosis are comparable to the results of a research by Korovessis and co-workers, where the angle from level Th_4 to Th_{12} was measured with the deBrunner Kyphometer on 90 adolescent subjects; an average angle of 44.7° was determined[8]. The linear correlation between both angles was moderate ($r=0.59$). Also the surface measurement of the sagittal spinal curvatures using the Myrin inclinometer showed comparable results, –46° for thoracic kyphosis and 32° for lumbar lordosis[18]. There are several data presenting X-ray measured sagittal curvatures which showed a different amount of differences: thoracic kyphosis 43.7° and lumbar lordosis 67.4°[27], thoracic kyphosis 25.4° (from 8° to 63°) and lumbar lordosis 29.0° (from 16° to 56°)[28].

In female subjects, a statistically significantly larger average thoracic kyphosis angle ($p=0.002$) and lumbar lordosis angle ($p<0.001$) was established in comparison with male subjects, which differs from the published observations[7,10]. In the contrary, two articles also report a bigger lumbar lordosis in women: an average of 13.2° bigger in women[29], an average lumbar lordosis in women 49.5° and in men 43.0°[30].

An analysis of sagittal curvatures angles between a younger and older group of subjects indicated that the average thoracic kyphosis angle ($p=0.428$) and the lumbar lordosis angle ($p=0.088$) do not significantly differ. In the indicated research of adolescents, the authors also did not establish a connection between age and thoracic kyphosis[10]. On the other hand, there are more articles where the increasing sagittal curvatures in older subjects are reported. In research of an older population of 61 women there was established a positive correlation between age and the thoracic kyphosis angle; however, it also included subjects with vertebral fractures[8]. The research on 100 healthy men and women showed an increase of thoracic kyphosis of 3° for every ten years[28]. Measurement of thoracic kyphosis in different age groups showed for both sexes at the age of 20 to 45 years 46.8°, between 46 and 70 years, 53° and in 75 years and older, 66°[31]. In 250 healthy women aged between 30 to 79 years the researchers found increasing thoracic kyphosis with age and the biggest difference in the age group 50 to 59 years[32].

A calculation of the linear correlation quotient of the observed angles and the Body Mass Index (BMI) indicated very weak but statistically significant correlations. The positive correlation between lumbar lordosis and the increasing BMI was detected in both sexes in one research[33], the other showed this only in women[34]. The statistically insignificant influence of BMI on the lumbar lordosis angle showed in the research on both sexes with an age span from 20 to 79 years[30].

The advantages of the measurements of the spinal sagittal curvatures on the body surface with the laser triangulation method are primarily the non-aggressiveness and non-contact of the measurement procedure, as well as the very good resolution of the incorporated points. The disadvantage is the measurement itself, which takes a couple of seconds and demands a still position of the subject and naturally provides only a statistical snapshot. Other technical solutions of recording can eliminate these deficiencies. Modern approaches are also directed towards an analysis of the entire 3D form of the back or even the body, which would connect the surface asymmetric forms with the non-physiological spine curvatures. There is a great need for research, development and clinical studies because the innovations form the basis of modern medicine[35].

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MJERENJE SAGITALNOG LUKA KRALJEŽNICE METODOM LASERSKE TRIANGULACIJE

S A Ž E T A K

Cilj prvog dijela istraživanja bio je utvrditi varijabilnost ponovljenih mjerenja u različitim mjernim uvjetima. U drugom dijelu, proveli smo na velikom broju bolesnika, mjerenje torakalne kifoze i lumbalne lordoze, te ih usporedili u odnosu na dob, spol i stupanj uhranjenosti. U prvom dijelu, mjerenja su provedena na plastičnom modelu leđa bolesnika s krutom i normalnom kralježnicom. U drugom dijelu u studiji je sudjelovalo 250 pacijenata (126 muškaraca i 124 žene). Za mjerenje zakrivljenosti kralježnice koristili smo aparat za lasersku triangulaciju konstruiran na Strojarskom fakultetu Sveučilišta u Ljubljani. Komparacija 30 ponovljenih mjerenja pokazuju prosječnu vrijednost ±2 SD što uključuje 95% rezultata.Trideset ponovljenih iščitavanja jednog 3D mjerenja: torakalna kifoza 41,2°±0,6°, lumbalna lordoza 4,4°±1,2°; 30 mjerenja na plastičnom modelu: torakalna kifoza 36,8°±1,2°, lumbalna lordoza 30,9°±2,0°; 30 mjerenja na pacijentima s krutom kralježnicom: torakalna kifoza 41,5°±2,4°, lumbalna lordoza 4,0°±1,8°; 30 mjerenja na pacijentima s normalnom kralježnicom: torakalna kifoza 48,8°±7,4°, lumbalna lordoza 21,1°±4,4°. Prosječna veličina torakalne kifoze u 250 pacijenata bila je 46,8° (SD 10,1°) i lumbalne lordoze 31,7° (SD 12,5°). Veličina kuta statistički je bila povezana sa spolom (povećan broj torakalne kifoze i lumbalne lordoze u žena) i indeksom tjelesne mase (povećan broj torakalne kifoze i lumbalne lordoze kod više uhranjenih pacijenata). Dob nije značajno korelirala s promatranim uglovima. Tijekom mjerenja kutova kralježnice bilo je važno obratiti pozornost na opuštanje i položaj pacijenta, kao i ponavljanje mjerenja koje pruža dobivanje prosječne vrijednosti. Dob i stupanj uhranjenosti utječu na veličinu sagitalnih kuteva kralježnice. U promatranom uzorku učinak dobi nije potvrđen.