Spinal alignment in low back pain patients and age-related side effects: a multivariate cross-sectional analysis of video rasterstereography back shape reconstruction data

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Abstract

Purpose Spinal form in the sagittal plane and asymmetries of spinal alignment in the frontal plane were identified earlier to be associated with low back pain. This study was aiming at investigating whether age was influencing the significance of these findings.

Methods Spinal alignment of 155 older and 58 younger low back pain patients was investigated using non-invasive video rasterstereography and compared to 192 pain free controls. Trunk inclination and imbalance, pelvis tilt and torsion, and the thoracic kyphosis and lumbar lordosis angle served as dependent variables, which were analyzed using multivariate procedures.

Results Frontal plane parameters—trunk imbalance ($\lambda > 0.60$) in combination with pelvis tilt ($\lambda > 0.64$)—constituted an independent component in a factor analysis model of spine shape parameters in younger and older patients, but not in pain free controls. Trunk imbalance (frontal), trunk inclination (sagittal) and partially thoracic kyphosis angle (sagittal) were extracted to separate patients from controls (discriminant coefficients > 0.50). Age could not be excluded as interfering variable for the lumbar lordosis angle. Significant univariate analyses revealed higher effect sizes for trunk imbalance and inclination ($\eta^2 > 0.07$) than for lordosis, kyphosis or pelvic parameters ($\eta^2 < 0.06$).

Conclusions In line with corresponding findings trunk imbalance remained a low back pain-associated parameter not depending on age. Over all, sagittal trunk inclination

and the thoracic kyphosis angle could not be established as being completely free from age influences, while the lumbar lordosis angle played a minor role and seemed to be influenced more by age than by low back pain in this rasterstereography study.

Keywords Spine shape · Low back pain · Age · Video rasterstereography · Multivariate analysis

Introduction

In the past, beside psychosocial components and physical activity items, also anthropometric factors could be established to be influencing factors for the development of low back pain. Especially, frontal plane spinal asymmetries were identified to be a risk factor for low back pain syndromes [2]. When the most predictive factor for the development of low back pain—earlier back pain periods—could be controlled statistically, a flatter lumbar lordosis angle could be identified as a risk factor [1]; mathematical modeling studies reported a tendency for a flatter lordosis angle in chronic low back pain patients, too [11]. Some radiological findings in adults confirmed a flatter lumbar lordosis to be associated with chronic low back pain [13]. However, controversy exists on this potential association [10, 15], and—despite clinical relevance—specific X-ray patterns between acute and chronic low back pain patients could not be identified for the lumbosacral transition [17]. A limited reliability of radiographic examinations, intraindividual variations in repeated measurements as well as multifactorial and individual influences on the sagittal spinal alignment should be taken into account while judging those results [13]. Furthermore, univariate analyses based on back surface examinations

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reported inconclusive results for low back pain-associated spine shape parameters [12, 18], although reliability of those methods was proved [8, 16, 20]. Multivariate approaches should probably be able to identify effects that could have been covered in univariate analyses by variable interdependencies.

Video rasterstereography provides an easy access to multivariate analysis procedures and is established as a valid method for a three-dimensional spinal form assessment [3–5]. Using video rasterstereography and multivariate analysis procedures, frontal plane (e.g., trunk imbalance and pelvis torsion) and sagittal plane (e.g., trunk inclination, lordosis angle) spine shape parameters could be identified to be associated with chronic low back pain in an adult population, ranging in age from 19 to 79 years [20–22]. In view of the corresponding literature, especially the sagittal plane parameters could have been affected by interfering influences of age [7, 9, 14, 19, 24]. The present investigation was aiming at separating age influences from low back pain-related spinal alignment deviations.

Materials and methods

Subjects

A total of 405 persons, low back pain patients ($n = 213$) and pain free controls ($n = 192$) could be recruited as volunteers (Table 1) having been explicitly informed about the investigation and the non-radiating character of physical examinations. Data were anonymized after the examination and analyzed for the purpose of a controlled cross-sectional design.

Patients came from outpatient rehabilitation and could be included after clinical and radiographic examinations by an orthopedic physician, who qualified the complaints as chronic unspecific back pain (LBP) whenever no correlation with structural or organic signs could be established and when patients had suffered from low back pain for a time period of 6 months minimum. In fact, back pain history varied from 6 months to more than 9 years (average 8 months); and most of the patients had gone through several clinical treatment trials before. Specific signs, such as vertebral fractures, spinal surgery, or acute sciatic symptoms and especially spinal disorders affecting the spinal alignment, e.g., Morbus Bechterev, Morbus Scheuermann or severe scoliosis, were exclusion criteria.

The controls were included if there was no diagnosis dealing with back pain complaints, no serious back pain history for 2 years, and no back pain at all in the last 6 months. Prior to the beginning of data acquisition in the year 2006, a cut-off was fixed for a reference sample of controls for an age interval, where the influence of growth (minimum 18 years of age) or degeneration (maximum 40 years of age) was supposed to be minimized [21]. In fact, age was ranging between 18 and 39 years within the controls. According to the purpose of this study, LBP patients were divided into a sample of under-40-year olds, ranging from 19 to 40 years (LBP under 40, $n = 58$) and a sample of patients older than 40 years (LBP over 40, $n = 155$), ranging from 41 to 79 years.

While there were no significant differences between younger male controls and patients in age or anthropometric data, we found significant differences between younger female controls and younger female patients: the controls were about 4.5 years younger ($P = 0.005$), their weight

Table 1 Anthropometrics for pain free controls (CON), younger low back pain patients (LBP under 40 years) and older low back pain patients (LBP over 40 years) for the whole sample and separated for males and females (mean $\pm$ standard deviation)

	Age (years)	Height (m)	Weight (kg)	BMI (kg/m ²)
Total				
CON ($n = 192$)	27.1 $\pm$ 4.5	1.79 $\pm$ 0.09	75.4 $\pm$ 10.1	23.5 $\pm$ 1.5
LBP under 40 ($n = 58$)	31.4 $\pm$ 6.9	1.78 $\pm$ 0.10	77.1 $\pm$ 9.9	24.2 $\pm$ 1.6
LBP over 40 ($n = 155$)	56.1 $\pm$ 10.6	1.72 $\pm$ 0.09	72.4 $\pm$ 8.7	24.5 $\pm$ 1.6
Females				
CON ($n = 79$)	26.5 $\pm$ 4.7	1.70 $\pm$ 0.06	65.7 $\pm$ 6.5	22.8 $\pm$ 1.5
LBP under 40 ($n = 31$)	32.1 $\pm$ 6.8	1.71 $\pm$ 0.05	70.4 $\pm$ 6.1	24.1 $\pm$ 1.6
LBP over 40 ($n = 98$)	56.3 $\pm$ 10.5	1.67 $\pm$ 0.06	67.2 $\pm$ 5.7	24.2 $\pm$ 1.7
Males				
CON ($n = 113$)	27.6 $\pm$ 4.4	1.85 $\pm$ 0.05	82.2 $\pm$ 5.5	24.0 $\pm$ 1.2
LBP under 40 ($n = 27$)	30.6 $\pm$ 7.1	1.87 $\pm$ 0.07	84.7 $\pm$ 7.6	24.2 $\pm$ 1.6
LBP over 40 ($n = 57$)	55.7 $\pm$ 10.7	1.81 $\pm$ 0.05	81.4 $\pm$ 4.8	24.9 $\pm$ 1.4

Values are in mean $\pm$ SD

BMI body mass index, SD standard deviation, n sample size

was about 5 kg less ($P = 0.001$), and their body mass index was about 1 kg/m² less ($P = 0.000$), too (Table 1).

Equipment

Spine shape parameters were calculated by means of video rasterstereography (Formetric®-System, Diers International, Schlangenbad, Germany), a non-radiating device for indirect and high resolution back shape reconstruction (reconstruction error 0.2–0.5 mm; resolution 10 pts/cm²) [5]. Reproducibility of back shape reconstruction was proved earlier [8, 16, 20]. Reliability coefficients for the spine shape parameters were ranging from 0.99 to 0.69 (Table 2).

Specific back surface landmarks—like the vertebra prominens (VP), the beginning of the rima ani representing the sacrum point (SP), and the right and left lumbar dimple (DR, resp. DL) representing the position of spinae iliaca posterior superior (SIPS) of the pelvis bones—were recognized automatically to build up a Cartesian coordinate system. This coordinate system served as calibration reference frame for a three-dimensional surface reconstruction using triangulation equations that insured a valid correlation between back shape reconstruction and radiographic assessments of the anatomy of spine and pelvis [3, 4]. For a better understanding of geometry and corresponding anatomical landmarks, spine shape parameters were illustrated in an animation (Fig. 1).

Statistics

Data were described as mean $\pm$ standard deviation (SD). Normal distribution was proved (Kolmogorov–Smirnov test). Pelvis inclination, thoracic kyphosis and lumbar lordosis angles were normally distributed over all subsamples, whereas trunk inclination, trunk imbalance, pelvis tilt and pelvis torsion were not normally distributed in all subsamples, due to the rectification of right (+) and left side (–) deviations of the symmetry line.

Factor analyses (principle components extraction, Kaiser normalization with varimax rotation) were conducted to identify almost independent factors describing the structure of spinal alignment by means of loading coefficients (λ) higher than 0.60. Discriminant analyses (independent variables entered together) were calculated to reveal spine shape parameters being able to separate samples from one another by means of standardized canonical discriminant coefficients higher than 0.50. Univariate analyses of variance were calculated, referring to an illustration of the samples' spine shape parameter profiles (Fig. 2). Significance was accepted for P values ≤ 0.05 . P values ≤ 0.10 assigned a statistical tendency.

Results

Factor analysis

For the pain free controls, three components could be extracted explaining 65 % of the total of the variance. The first factor described the sagittal plane, determined by trunk inclination ($\lambda = -0.69$), thoracic kyphosis angle ($\lambda = 0.74$) and lumbar lordosis angle ($\lambda = 0.74$). The second component described the pelvis position determined by pelvis tilt ($\lambda = 0.82$) and pelvis torsion ($\lambda = 0.77$). The third component was determined by trunk imbalance ($\lambda = 0.96$) describing the upper body orientation in the frontal plane (Table 3).

For younger and older low back pain patients, only two independent components were extracted explaining 47 and 50 % of the total of the variance, respectively. The first component described the sagittal plane by means of the thoracic kyphosis angle (LBP under 40: $\lambda = 0.78$, LBP over 40: $\lambda = 0.88$) and the lumbar lordosis angle (LBP under 40: $\lambda = 0.82$, LBP over 40: $\lambda = 0.82$), comparable to the pain free controls, while trunk inclination was no longer part of this independent component. The second component described the upper body orientation in the

Table 2 Spine shape parameters, shortcuts with intraclass correlation coefficient (ICC), and a description of anatomy and corresponding geometry

Spine shape parameter	Short/ICC	Explication
Trunk imbalance (mm)	Tr_imb/ICC = 0.82	Plumb line deviation from VP to DM in the frontal plane (Fig. 1)
Trunk inclination (mm)	Tr_inc/ICC = 0.91	Plumb line deviation from VP to DM in the sagittal plane (Fig. 1)
Pelvis tilt (mm)	P_tilt/ICC = 0.81	Deviation of the axis of lumbar dimples to the floor line in the frontal plane (Fig. 1)
Pelvis torsion (°)	P_tors/ICC = 0.69	Torsion between left and right side pelvis bones (os ilium)
Kyphosis angle (ICT–ITL) (°)	KA_max/ICC = 0.91	Maximum thoracic angle calculated from ICT and ITL triangles (Fig. 1)
Lordosis angle (ITL–ILS) (°)	LA_max/ICC = 0.99	Maximum lumbar angle calculated from ITL and ILS triangles (Fig. 1)

VP vertebra prominens, DM midpoint between dimples, ICT inflectional point of the curvature from cervical to thoracic spine, ITL inflectional point of the curvature from thoracic to lumbar spine, ILS inflectional point of the curvature from lumbar to sacral spine

Fig. 1 Illustration of spinal alignment and back shape reconstruction parameters (Table 2) and the corresponding in vivo back shape with projection lines. It is shown here with *highlighted landmarks* (vertebra prominens and dimples) for demonstration (modified from [21])

Fig. 2 Profile of spinal alignment parameters for the subsamples of the controls (CON), the low back pain (LBP) patients under 40 and over 40 years of age, and separated for males and females in the lumbar lordosis angle: **a** trunk inclination, trunk imbalance and pelvis tilt, **b** pelvis torsion, thoracic kyphosis and lumbar lordosis angles.

Tr_inc trunk inclination (mm), *Tr_imb* trunk imbalance (mm), *P_tilt* pelvis tilt (mm), *P_tors* pelvis torsion (°), *KA* kyphosis angle (°), *LA* lordosis angle (°), *n.s.* $P > 0.05$, (*t*) $P \leq 0.10$, $*P \leq 0.05$, $**P \leq 0.01$, $***P \leq 0.001$

frontal plane as a combination of trunk imbalance (LBP under 40: $\lambda = 0.64$, LBP over 40: $\lambda = 0.60$) and pelvis tilt (LBP under 40: $\lambda = 0.64$, LBP over 40: $\lambda = -0.66$), meaning that frontal plane upper body deviations were affected by pelvis deviations in low back pain patients, not depending on the age (Table 3).

Discriminant analysis

The samples of the controls and the younger patients—of similar age—could be separated correctly for 69.4 % of the

grouped cases (canonical correlation 0.332, Wilks' Lambda 0.890, $P = 0.000$) by means of trunk inclination, trunk imbalance and thoracic kyphosis angle (discriminant coefficients >0.50). The samples of the controls and the older patients—of different age—could be separated correctly for 68.7 % of the grouped cases (canonical correlation 0.420, Wilks' Lambda 0.824, $P = 0.000$) by means of trunk inclination and trunk imbalance (discriminant coefficients >0.50). The samples of the younger patients and the older patients could be separated correctly for 64.8 % of the grouped cases (canonical correlation 0.293, Wilks'

Table 3 Rotated component matrices for the total of controls and the total of LBP patients under 40 years of age and over 40 years of age by factor analysis procedure

	Controls (<i>n</i> = 187) components			LBP over 40 (<i>n</i> = 155) components		LBP under 40 (<i>n</i> = 58) components	
	1	2	3	1	2	1	2
Tr_inc	−0.69	−0.04	0.14	−0.33	0.49	−0.01	−0.57
Tr_imb	−0.03	0.04	0.96	−0.03	0.64	0.21	0.60
P_tilt	0.09	0.82	−0.05	0.09	0.64	0.15	−0.66
P_tors	−0.13	0.77	0.08	0.38	0.42	0.25	0.50
KA	0.74	−0.06	0.30	0.78	0.08	0.88	−0.01
LA	0.74	−0.05	−0.08	0.82	−0.13	0.82	0.15
Variance explained	65.3 %			46.7 %		49.6 %	

Kaiser normalization, varimax rotation, factor loading coefficients (λ) ≥ 0.60 in *italics*

Table 4 Canonical discriminant coefficients for the total of controls vs. LBP patients under 40 years, controls vs. LBP patients over 40 years, and LBP patients under 40 vs. over 40 years

	Canonical discriminant coefficients		
	CON vs. LBP under 40	CON vs. LBP over 40	LBP under vs. over 40
Tr_inc	0.51	0.63	0.28
Tr_imb	0.57	0.70	0.35
P_tilt	0.34	−0.11	−0.43
P_tors	−0.06	0.28	0.22
KA	−0.66	−0.03	0.79
LA	0.23	0.19	−0.16

Independent variables entered together, discriminant coefficients ≥ 0.50 in *italics*

Lambda 0.914, $P = 0.005$) by means of the thoracic kyphosis angle, meaning that trunk imbalance and trunk inclination were extracted as low back pain indicators not depending on age, whereas the thoracic angle indicated low back pain in case of a flatter kyphosis (discriminant coefficient −0.66) for younger people, and age within the patients being determined by a rounder thoracic spine (discriminant coefficient 0.79) (Table 4).

Univariate analyses

Video rasterstereography spine shape parameters were illustrated as a spinal profile for pain free controls and low back patients of different age (Fig. 2). Corresponding univariate analyses revealed significant differences between the subsamples regardless of variable interdependencies.

For two spine shape parameters, there was a higher effect size: trunk imbalance ($F = 18.925$, $P = 0.000$, $\eta^2 = 0.086$) and trunk inclination ($F = 15.495$, $P = 0.000$, $\eta^2 = 0.072$). For pelvis torsion, thoracic kyphosis, and lumbar lordosis (males), F values were significant ($P < 0.01$), but effect size was < 0.06 (Table 5):

- Trunk inclination: significantly lower for controls compared to older patients ($P = 0.017$) and younger patients ($P = 0.000$), no significance within the patients ($P = 0.786$).
- Trunk imbalance: significantly less for controls compared to older patients ($P = 0.000$) and less (statistical tendency) compared to younger patients ($P = 0.066$), no significance within the patients ($P = 0.117$).
- Pelvis torsion: significantly less only for controls compared to older patients ($P = 0.008$).
- Kyphosis angle: significantly flatter for the younger patients compared to controls ($P = 0.004$) and older patients ($P = 0.004$).
- Lordosis angle: significantly flatter only for the older male patients compared to the male controls ($P = 0.013$).

Discussion

Earlier investigations identified frontal plane asymmetries to be associated with unspecific LBP using multivariate analyses [20–22]. The target of the present investigation was to determine the role of age for this topic, although age should not be considered to be the sole factor for spinal degeneration [6]. So far frontal plane parameters have not been assumed to be depending on age [7, 9, 14, 19, 24].

In factor analyses, we found rotated component models that were comparable within the patients' subsamples, but different from the controls. Younger patients as well as older ones showed a component where trunk imbalance was no longer an independent factor describing the frontal plane, but was combined with pelvis tilt affecting the frontal plane deviation (Table 3). Trunk imbalance could also be extracted as a frontal plane parameter, discriminating pain free controls from younger as well as from older LBP patients (Table 4). These results were probably

Table 5 Descriptions and results of a 1-way ANOVA for the subsamples of the controls ($n = 192$) and the LBP patients under 40 ($n = 58$) and over 40 years of age ($n = 155$) and separately in thelumbar lordosis angle for males (CON $n = 113$, LBP under 40 $n = 27$, LBP over 40 $n = 57$) and females (CON $n = 79$, LBP under 40 $n = 31$, LBP over 40 $n = 98$)

	Mean $\pm$ SD	ANOVA			Post hoc Bonferoni		
		F	P	η^2	Group wise	Difference	P
Tr_inc (mm)							
CON	10.0 $\pm$ 16.2	15.495	0.000	0.072	con-u40	−8.1	0.017
LBP under 40	18.0 $\pm$ 20.4				con-o40	−11.4	0.000
LBP over 40	21.4 $\pm$ 22.3				u40-o40	−3.3	0.786
Tr_imb (mm)							
CON	7.5 $\pm$ 5.8	18.925	0.000	0.086	con-u40	−2.4	0.066
LBP under 40	9.8 $\pm$ 7.6				con-o40	−4.6	0.000
LBP over 40	12.1 $\pm$ 7.8				u40-o40	−2.2	0.117
P_tilt (mm)							
CON	4.9 $\pm$ 4.3	1.374	0.254	0.007	con-u40	−1.0	0.360
LBP under 40	5.8 $\pm$ 4.2				con-o40	0.0	1.000
LBP over 40	4.8 $\pm$ 4.0				u40-o40	1.0	0.373
P_tors (°)							
CON	2.6 $\pm$ 2.2	4.722	0.009	0.023	con-u40	−0.2	1.000
LBP under 40	2.8 $\pm$ 2.2				con-o40	−0.8	0.008
LBP over 40	3.4 $\pm$ 2.9				u40-o40	−0.6	0.286
KA (°)							
CON	48.1 $\pm$ 9.2	6.032	0.003	0.029	con-u40	4.4	0.004
LBP under 40	43.8 $\pm$ 7.9				con-o40	−0.1	1.000
LBP over 40	48.2 $\pm$ 8.9				u40-o40	−4.4	0.004
LA male (°)							
CON	35.7 $\pm$ 6.5	5.171	0.006	0.051	con-u40	3.0	0.115
LBP under 40	32.7 $\pm$ 6.8				con-o40	3.1	0.013
LBP over 40	32.5 $\pm$ 6.8				u40-o40	0.2	1.000
LA female (°)							
CON	42.3 $\pm$ 8.3	0.095	0.909	0.001	con-u40	0.7	1.000
LBP under 40	41.6 $\pm$ 7.7				con-o40	0.5	1.000
LBP over 40	41.8 $\pm$ 9.5				u40-o40	−0.2	1.000

not affected by age-related side effects, although significance failed by 1.6 % for the comparison of controls and younger patients in a univariate analysis (Table 5). This result was in line with findings that revealed frontal plane asymmetries as risk factor for the development of low back pain [1, 2].

In terms of our rasterstereography spinal form assessment, sagittal plane spine shape parameters could not be exposed clearly by multivariate factor analysis procedures as LBP indicating variables, but in discriminant analyses sagittal plane parameters were extracted as variables being able to separate controls from LBP patients of different age (Table 4). Trunk inclination could be assumed to indicate LBP without age-related side effects, but the other sagittal plane parameters might be depending on age as well as on low back pain, as the lumbar lordosis was flatter only in the sample of the older male patients, and the thoracic

kyphosis was flatter only in the sample of the LBP patients under 40 years of age, while older patients had a rounder thoracic spine than younger patients (Table 5).

So, age influences in the sagittal plane were apparent on the one hand in this study of LBP patients showing no structural or organic back pain correlates, which were in line with corresponding investigations that found different modes of systematic age-related spine shape changes depending on the pelvic position type. In case of incongruent relations between pelvis inclination and lumbar lordosis angle, increases of thoracic angles could be observed in the time course of aging, meaning a rounder kyphosis [14]. Comparable findings could be established for age-related decreases of the lumbar angle, meaning a flatter lordosis [7, 24]. On the other hand, there might be an assessment-related influence, especially affecting our results of lumbar lordosis angles. Recent research, using

lateral photography with manually placed markers on bony structures and no X-ray imaging, revealed a more neutral sagittal curvature as being correlated with less pain [23]. Maybe, interindividually varying soft tissue thickness—especially fat and muscles in the lumbar back region—partially covered specific bony spinal alignment patterns in the indirect spine shape reconstruction based on surface topography, although rasterstereography was validated in terms of X-ray comparisons [3–5]. This could possibly explain why we did not find systematic effects for a flatter lordosis in younger patients comparable to radiological studies [1, 13].

Conclusions

Using video rasterstereography and multivariate analysis procedures, we found low back pain-associated spine shape parameters in the frontal plane, which was consistent with findings considering frontal plane asymmetries to be risk factors for the development of low back pain [1, 2]. Parameters of the sagittal plane were extracted as being associated with low back pain, too. But with respect to the literature and inconsistency of different multivariate analysis approaches, those parameters also might to some extent be affected by aging and degeneration [7, 9, 14, 19, 24]. Despite assessment-specific limitations for the lumbosacral transition and despite a missing subsample of older controls, due to the inclusion criterion set prior to the investigation, we conclude that frontal plane trunk imbalance remains a low back pain indicator irrespective of age, while it was not possible to tell if it is the cause or a symptom of unspecific low back pain complaints.

Conflict of interest None.

References

- Adams M, Mannion A, Dolan P (1999) Personal risk factors for first time low back pain. *Spine* 24:2497–2505
- Balagué F, Troussier B, Salminen J (1999) Non-specific low back pain in children and adolescents: risk factors. *Eur Spine J* 8:429–438
- Drerup B, Hierholzer E (1987) Automatic localization of anatomical landmarks on the back surface and construction of a body-fixed coordinate system. *J Biomech* 20:961–970
- Drerup B, Hierholzer E (1987) Movement of the human pelvis and displacement of related anatomical landmarks on the body surface. *J Biomech* 20:971–977
- Drerup B, Hierholzer E (1994) Back shape measurement using video rasterstereography and three-dimensional reconstruction of spinal shape. *Clin Biomech* 9:28–36
- Ferguson SJ, Steffen T (2003) Biomechanics of the aging spine. *Eur Spine J* 12(Suppl.2):S97–S103
- Gelb D, Lenke L, Bridwell K, Blanke K, McEnery K (1995) An analysis of sagittal spinal alignment in 100 asymptomatic middle and older aged volunteers. *Spine* 20:1351–1358
- Goh S, Price RI, Leedman PJ, Singer KP (1997) Rasterstereographic analysis of the thoracic sagittal curvature: a reliability study. *J Musculoskelet Res* 3:137–142
- Goh S, Tan C, Price RI, Edmondston SJ, Song S, Davis S, Singer KP (2000) Influence of age and gender on thoracic vertebral body shape and disc degeneration of 169 cases. *J Anatomy* 197:647–657
- Harreby M, Neergaard K, Hesselsoe G, Kjer J (1995) Are radiologic changes in the thoracic and lumbar spine of adolescents risk factors for low back pain in adults? *Spine* 20:2298–2302
- Harrison DD, Cailliet R, Janik T, Troyanovich S, Harrison DE, Holland C (1998) Elliptical modeling of the sagittal lumbar lordosis and segmental rotation angles as a method to discriminate between normal and low back pain subjects. *J Spinal Disord* 11:430–439
- Heckmann T, Tschann H, Kinzlbauer M, Guschelbauer R, Bachl N (2008) Analyse der Körperhaltung bei Jugendlichen mit Hilfe der Videorasterstereographie unter Berücksichtigung der Prävalenz des Rückenschmerzes und der körperlichen Aktivität. *Österr. J Sportmed* 38:25–36
- Jackson R, Kanemura T, Kawakami N, Hales C (2000) Lumbopelvic lordosis and pelvic balance on repeated standing lateral radiographs of adult volunteers and untreated patients with constant low back pain. *Spine* 25:575–586
- Kobayashi T, Atsuta Y, Matsuno T, Takeda N (2004) A longitudinal study of congruent sagittal spinal alignment in an adult cohort. *Spine* 29:671–676
- Korovessis P, Koureas G, Papazisis Z (2004) Correlation between backpack weight and way of carrying, sagittal and frontal spinal curvatures, athletic activity, and dorsal and low back pain in schoolchildren and adolescents. *J Spinal Disord* 17:33–40
- Mohukum M, Wolf U, Mendoza S, Paletta J, Sitter H, Skwara A (2009) Reproducibility of rasterstereography for kyphotic and lordotic angles and for trunk length and trunk inclination—a reliability study. *Eur Spine J* 18:1746
- Nakipoglu G, Karagöz A, Özgürin N (2008) The biomechanics of the lumbosacral region in acute and chronic low back pain patients. *Pain Phys* 11:505–511
- Nourbakhsh M, Arabloo A, Salavati M (2006) The relationship between pelvic cross syndrome and chronic low back pain. *J Back Musculoskelet* 19:119–128
- Ostrowska B, Rozek-Mrozand K, Gienza C (2003) Body posture in elderly, physically active males. *Aging Male* 6:222–229
- Schroeder J, Mattes K (2012) Spinal alignment and low back pain indicating spine shape parameters. In: Sakai Y (ed) *Low back pain—pathogenesis and treatment*, InTech, Rijeka, Croatia, open access: <http://www.intechopen.com/articles/show/title/spinal-alignment-and-low-back-pain-indicating-spine-shape-parameters>
- Schröder J, Stiller T, Mattes K (2010) Spine shape parameters as indicators for low back pain disorders. *Dtsch Z Sportmed* 61:91–96
- Schröder J, Strübing K, Mattes K (2010) Back complaints and spinal form. *Manuelle Med* 48:454–459
- Smith A, O'Sullivan P, Straker L (2008) Classification of sagittal thoraco-lumbo-pelvic alignment of adolescent spine in standing and its relationship to low back pain. *Spine* 33:2101–2107
- Takeda N, Kobayashi T, Atsuta Y, Matsuno T, Shirado O, Minami A (2009) Changes in the sagittal spinal alignment of the elderly without vertebral fractures: a minimum 10-year longitudinal study. *J Orthop Sci* 14:748–753