Spinal Alignment and Low Back Pain Indicating Spine Shape Parameters

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1. Introduction

Low back pain is thought of as having no structural correlates in radiographic findings. But an associated deconditioning syndrome is assigned by back pain complaints accompanied by functional deficits, especially peak force and performance deficits of deep trunk muscles. We were aiming at investigating if there might be comparable relations between spinal mal-alignment and complaints in chronic low back pain patients. And if spine shape aberrations were in fact associated with low back pain, could they be used to determine exercise programs for an active low back pain therapy, as is generally known for diagnostic screening procedures and low back pain therapy monitoring based on muscle function deficits? Seeking for exercise induced adaptations, we intended to find statistical correlations indicating some kind of specificity for those individualized exercise programs which are based on initial findings in spinal alignment and trunk muscle function.

Our scientific approach involved two aspects that were important for both practical applications and scientific analysis methods in the field of low back pain treatment and research. First of all, our spine shape assessment was non-invasive, and therefore suitable for screening and monitoring without any risks for patients and volunteers. And secondly, indirect spine shape assessment by means of video raster stereography allowed an easy access to multivariate statistical analysis approaches. Therefore, variable interdependencies could be taken into account which might have covered significant effects in earlier investigations.

2. Background

From an economic point of view, low back pain (LBP) is one of the most emerging and cost-pushing health disorders in the western world, and for the majority of cases neither direct organic signs nor structural correlates can be identified (Waddell et al., 1980). According to McGill (2007, p. 5), more than 80% of all patients with back complaints suffer from non-specific low back pain. He suggests that, besides other factors, insufficient diagnosis procedures may contribute to the current uncertainty regarding the true incidence of specific low back pain issues.

Several influencing factors are discussed to be essential in the etiology of low back pain, such as psycho-social components (Waddell et al., 1980), and organic mechanisms in terms of spinal instability due to ligament function and deficits in neuromuscular coordination and compensation: neutral zone spinal instability hypothesis (Panjabi, 1992).

With respect to these biomechanical and social-medical findings, and being aware of muscular dysfunction in LBP patients compared to pain free volunteers (Cady et al., 1979; Denner, 1997; McNeil et al., 1980), reconditioning of muscle function and neuromuscular coordination patterns is supposed to be a successful intervention mode in the therapy of low back pain (Denner, 1997; McGill, 2007; Panjabi, 1992; Waddell et al., 1980), especially when segmental stabilization is taken into account (Ljunggren et al., 1997; O'Sullivan, Twomey & Allison, 1997; Richardson, Hodges & Hides, 2004).

Beside deficits in muscle function of LBP patients, there are anthropometric risk factors for the development and progredience of LBP which deal with spinal shape asymmetries in the frontal plane (Balagué, Troussier & Salminen, 1997) and the alignment of the lumbosacral transition in the sagittal plane (Adams, Mannion & Nolan, 1997; Lewit, 1991, p. 60). Video raster stereographic back shape reconstruction offers a valid and reliable and – in contrast to radiographic screening procedures – a non-invasive, non-aggressive high-resolution system for spine shape assessment in screening and monitoring (Drerup & Hierholzer, 1994).

Recent video raster stereographic investigations of the spinal form of male and female LBP patients and pain free volunteers revealed spine shape parameters indicating LBP by means of multivariate factor analyses: trunk imbalance and trunk inclination (Schröder, Stiller & Mattes, 2010). While a more extended trunk inclination should be considered to be due to the higher age of the patients (Gelb et al., 1995; Kobayashi et al, 2004; Takeda et al., 2009), trunk imbalance remained as a marker for low back pain. Additionally, there was some evidence for a flatter lumbar lordosis in male patients, revealed by means of discriminant analyses (Schröder, Strübing & Mattes, 2010). With female patients, too, pelvis torsion and pelvis tilt were found to be indicating low back pain (Schröder, Stiller & Mattes, 2011). It is highly probable that video raster stereography offers some possibilities in the process of differential diagnosis of sacroiliac disorders (Foley & Buschbacher, 2006).

Furthermore, there was some evidence for non-parametric signs in the spinal alignment of back pain patients with vertebral blockades (Schröder, Färber & Mattes, 2009) or a lumbar facet joint syndrome (Schröder, Strübing & Mattes, 2010). These findings and some specific kind of profile of spinal shape parameters should be helpful for diagnosis procedures in the field of orthopaedic practioneers. This work is in process.

The findings mentioned above might provide an opportunity to create therapeutic exercise programs based on spinal form deviation signs, comparable to individualized exercise programs based on muscle function deficits (Denner, 1997). So far, specific correlations between adaptations of muscle function and clinical out-come parameters could hardly be established (Mannion et al., 2001b; 2001c). Nevertheless, first results of a pilot study seemed to show specific adaptations following individualized exercise programs, e.g. trunk imbalance decreased mainly in patients who showed extraordinary values in the frontal plane before a short-term training period of ten weeks. This specific decrease correlated with pain reduction and was accompanied by increases in peak forces of trunk muscle strength (Schröder et al., 2009).

In general, spinal form adaptations are difficult to prove by means of statistical calculations (Kuo, Tully & Galea, 2009), because they depend on the degree of mal-alignment, and adaptations are varying considerably among individuals (Weiß, Dieckmann & Gerner, 2003; Weiß & Klein, 2006). Age and gender also seem to be influencing factors for the degree of spinal form adaptations in some parameters (Schröder & Mattes, 2010). Correlations between clinical out-come and muscle function increases are augmented, when spinal form adaptations are taken into account in multiple regression models.

3. Methods

3.1 Study design

First of all, a cross-sectional study was conducted to identify spine shape parameters associated with low back pain. Secondly, a pre-post-effect analysis was carried out, seeking for exercise induced adaptations in the process of reconditioning.

3.2 Subjects

At least 405 subjects could be examined, 213 patients suffering from low back pain (LBP) and 192 volunteers – most of them freshmen at the University of Hamburg – serving as controls (CON). The controls were included if there was no diagnosis dealing with back pain complaints, no serious back pain history for two years, and no back pain at all in the last six months.

Participants were divided into female and male subsamples. Due to the large sample size, the observed – relatively small – differences in anthropometric parameters between patients and controls were almost significant, except for the body weight of the males (tab. 1).

	age [y]	height [m]	weight [kg]	BMI [kg/m²]
LBP females	50,5	1,68	67,9	24,2
SD (n=129)	14,2	0,06	6,0	1,6
LBP males	47,6	1,83	82,4	24,6
SD (n=84)	15,3	0,06	6,0	1,4
CON females	26,5	1,70	65,7	22,8
SD (n=79)	4,7***	0,06*	6,5*	1,4***
CON males	27,6	1,85	82,2	24,0
SD (n=113)	4,4***	0,05**	5,5	1,2***

Table 1. Anthropometric data of low back pain patients (LBP) and pain free controls (CON) (mean ± standard deviation; LBP vs. CON: * p≤0,05; ** p≤0,01; *** p≤0,001 Student's t-test)

Female patients were significantly older (t = -17,636; p < 0,000), had a slightly smaller body height (t = 2,475; p = 0,014), a slightly larger body weight (t = -2,517; p = 0,013) than the female controls and also showed a slightly higher body mass index (t = -6,353; p < 0,000).

Male patients were significantly older (t = -11,668; p < 0,000), had a slightly smaller body height (t = 2,395; p = 0,018), a nearly identical mean body weight (t = -0,330; p = 0,742), and showed a slightly higher body mass index (t = -3,298; p < 0,001), too (tab. 1).

Patients were included after clinical and radiographic examinations by an orthopaedic physician (Buchholz & Partner, Hamburg, Germany), who qualified the pain syndrome as chronic unspecific back pain (LBP), when no correlation to structural signs could be established and when patients suffered from low back pain for a time period of six months minimum. In fact, back pain history varied from six months to more than nine years (average: 8 months) and most of the patients had gone through several treatment trials before. Specific signs, such as vertebral fractures, spinal surgery, severe scoliosis or acute sciatic symptoms were exclusion criteria, as well as a back pain state of more than 5 points in the CR10 pain scale reacing from zero to ten points (Borg, 1998) at examination time.

107 of those patients mentioned above went through an exercise therapy program and were re-examined in a post-test. Treatment effects could be analysed for 61 female patients (57%), and for 46 males (43%). Females were 48,7 ± 14,1 years of age, body height was 1,70 ± 0,07 m, body weight was 67,8 ± 10,7 kg, and their body mass index (BMI) was 23,6 ± 3,3 kg/m². Males were of the same age (49,6 ± 14,3 years), but naturally higher (1,80 ± 0,07 m) and heavier (81,4 ± 12,9 kg), while the body mass index was comparable (24,9 ± 2,9 kg/m²) to the females, and not indicating obesity.

3.3 Spine shape assessment

Spine shape parameters were calculated by means of video raster stereography (Formetric®-System[1]), a high resolution back shape reconstruction device (reconstruction error 0,2 to 0,5 mm; resolution 10 pts./cm²) (Drerup & Hierholzer, 1994). Reproducibility of back shape reconstruction was proved. Reliability coefficients (ICC: Intra Class Correlation) were ranging between 0,99 and 0,91 for the sagittal plane, and between 0,82 and 0,69 for the frontal plane. For the coronal plane, reliability was 0,81 (Mohukum et al., 2009; Schröder & Mattes, 2009; Schröder, Reer & Mattes, 2009) (tab. 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 - 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 ensured a valid correlation between back shape reconstructions and radiographic assessments of the anatomy of spine and pelvis characters [2] (Drerup & Hierholzer, 1985; 1987a; 1987b) (fig. 1).

[1] Diers International, Schlangenbad, Germany

[2] Using stereography, the three-dimensional coordinates of every point on a given surface might be calculated by two cameras. In video raster stereography one camera is substituted by a projector – quasi like an inverse camera (fig. 1). If the geometry of projector and camera is known and invariant, triangulation equations enable the system not only to detect every point on the back surface, but also to reconstruct invariant back shape characters based on two phenomenons: First of all, the surface around every point spreads into two directions. The curvature of these planes may be calculated from the three-dimensional coordinates of any reconstruction point. As a consequence, the surface of the reconstructed body may show nothing but a convex, a concave or a saddle-shaped curvature as an invariant representation of the back shape (fig. 1), not depending on the position of the reconstructed body. Additionally, every point on the surface has an orientation determined by structures beneath the skin surface, which can be expressed mathematically by the surface normal. For back shape reconstruction, the spinous processes and the lumbar dimples representing pelvic processes are of a certain interest (fig. 1) (Drerup et al., 2001).

Spine shape parameter	Short/ ICC	Explication
Trunk imbalance [mm]	Tr-Imb ICC=0,82	Plumb deviation from vertebra prominens to midpoint between dimples in the frontal plane (fig. 2)
Trunk inclination [mm]	Tr-Inc ICC=0,91	Plumb deviation from vertebra prominens to pelvis position/ midpoint between dimples in the sagittal plane (fig. 2)
Pelvis tilt [mm]	P-Tilt ICC=0,81	Deviation of the axis of lumbar dimples to the floor line in the frontal plane (fig. 2)
Pelvis torsion [°]	P-Tors ICC=0,69	Relative torsion between left and right side pelvis bones (os ilium) in the frontal-transversal plane
Vertebral side deviation [mm]	Side-rms ICC=0,71	Average deviation of vertebral bodies in the frontal plane (rms from vertebra prominens to midpoint between dimples)
Vertebral rotation (rms) [°]	Rot-rms ICC=0,81	Average rotation of vertebral bodies in the transversal plane (rms from vertebra prominens to midpoint between dimples)
Kyphosis angle (ICT-ITL) [°]	KA-max ICC=0,91	Maximum thoracic angle calculated from ICT and ITL triangles (fig. 2)
Lordosis angle (ITL-ILS) [°]	LA-max ICC=0,99	Maximum lumbar angle calculated from ITL and ILS triangles (fig. 2)

Table 2. Spine shape parameters, short-cuts with Intra Class Correlation coefficient (ICC), and a description of anatomy and corresponding geometry

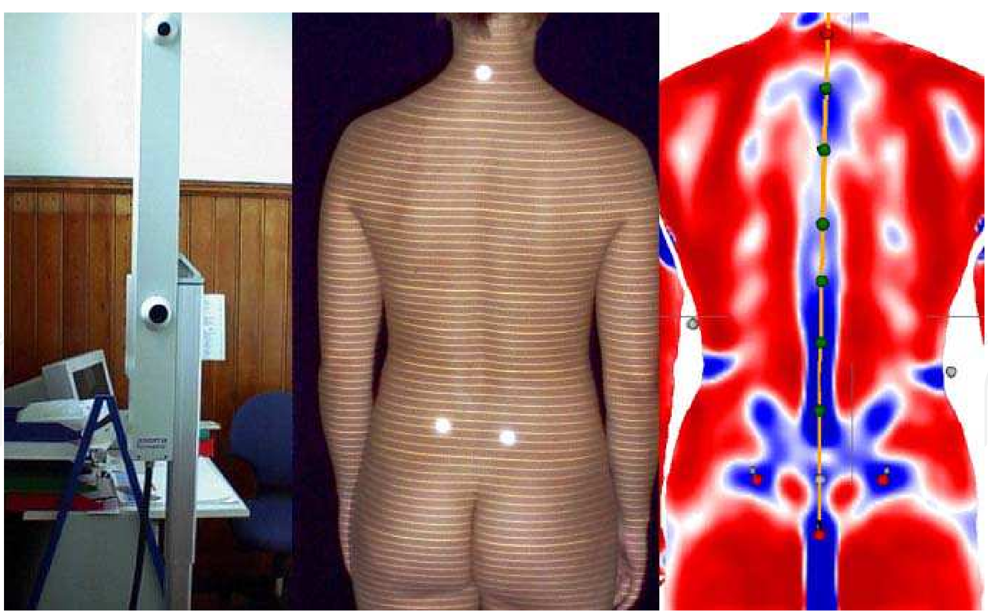


Fig. 1. Video raster stereography with camera and projector system (left), projection lines on the back surface with vertebra prominens (VP) and lumbar dimples (DL+DR) high-lighted - here with optical markers only for demonstration (middle), and video raster stereography back surface reconstruction with landmarks recognized automatically (red dots) and plane curvatures representing convex (red areas) or concave (blue areas) back shape profiles (right) (modified from: Schröder, Förster & Mattes, 2008, p. 46)

For a better understanding of geometry and corresponding anatomical landmarks, spine shape parameters were illustrated in an animation, especially for the sagittal plane (fig. 2).

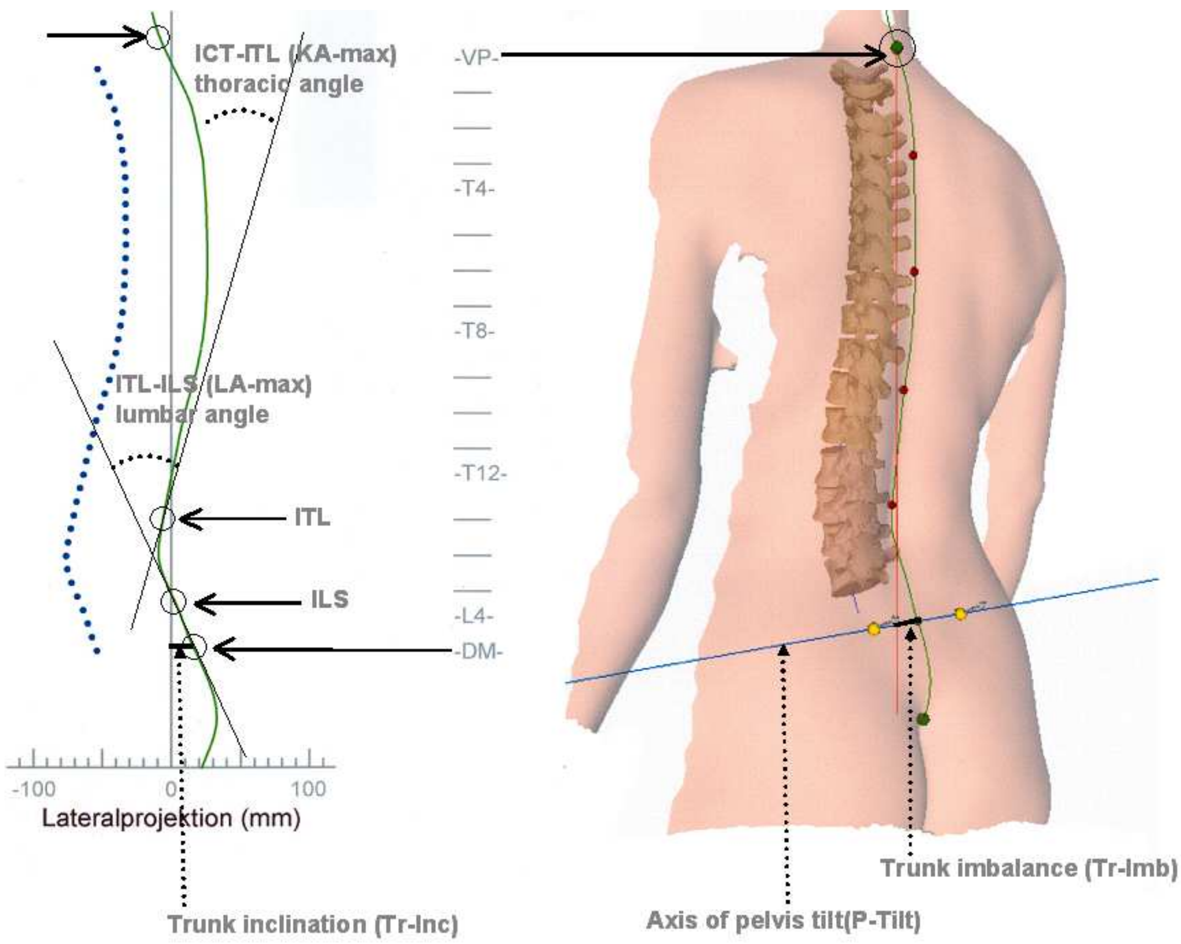


Fig. 2. Spine shape in the sagittal plane: kyphosis angle (KA-max) and lordosis angle (LA-max) with inflectional points of the curvature from cervical to thoracic spine (ICT), from thoracic to lumbar spine (ITL) and from lumbar to sacral spine (ILS) and three dimensional animation of back surface with lumbar dimples (yellow dots – with arrows representing the direction of the mathematical normal on each dimple's plane) and spinous processes like vertebra prominens (VP) and sacrum point (SP) marking the beginning of the rima ani (green dots) (Formetric®-System) (modified from: Schröder, Stiller & Mattes, 2010, p. 92)

3.4 Trunk muscle peak force assessment

Torques of the superficial trunk muscles were assessed by means of isometric peak forces (sensor sample rate 100 Hz, sensibility 0,85 mV/V, signal smoothing by a sliding average over 0,3 sec) in a test chair that allowed data acquisition in all three dimensions (extension-flexion, lateral flexion, axial rotation) (Myoline®)[3], while patients or volunteers had to be fixed only once for all test contractions in a universal standard position. Reproducibility was verified, and reliability coefficients were ranging between 0,85 and 0,94 for trunk muscle testing in all three dimensions (Schröder, Reer & Mattes, 2009).

[3] Diers International, Schlangenbad, Germany

3.5 Pain documentation

Pain was described by means of the CR10 pain scale questionnaire, an instrument for self-rated pain and exertion, evaluated by Gunnar Borg (1998). The CR10 pain scale (0=nothing at all, 0,5=extremely weak, 1=very weak, 2=weak, 3=moderate, 5=strong, 7=very strong and 10=extremely strong) combined categorical and rational aspects of the phenomenon pain – for a valid assessment with respect to the non-linear relation between pain state and semantic expressions for its description[4]. Reliability had been verified earlier, and coefficients ranged between 0,78 to 0,99 (Borg, 1998, pp. 41-43).

3.6 Treatment

About 50% of all low back pain patients (n=107) went through an individualized exercise program for a time period of 10 to 12 weeks from pre- to post-testing. There were 18 training sessions altogether, normally two sessions per week. Every session took 60 minutes and followed a fixed schedule of seven phases: a systematic ergometer warm-up (5 min), functional strengthening (2 to 4 exercises) and stretching (4 to 6 exercises), as well as physiotherapist pulley and weight training (4 to 6 exercises) using standard training devices. But the exercise program was dominated by Segmental Stabilization Training (SST), which was learned and re-learned in every session (2 to 3 min) in a basic exercise (fig. 3), and which was applied in several static (2 to 4 exercises) and dynamic (2 to 3 exercises) tasks with an emphasis on the special SST-coordination[5] pattern.

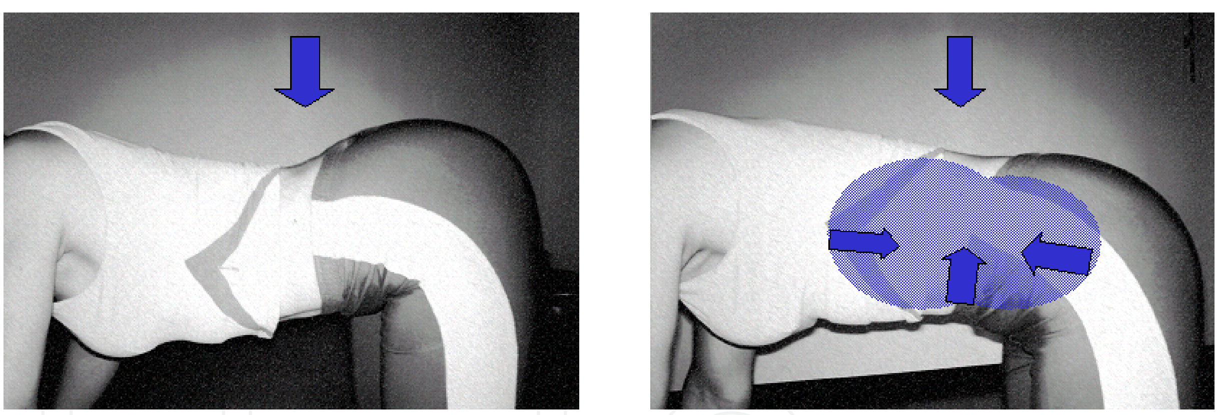


Fig. 3. Coordination pattern of Segmental Stabilization Training (SST) (from: Schröder, Förster & Mattes, 2008, p. 48)

[4] As there is no linear relation between increasing pain and expressions for its description, the CR10 pain scale has a higher rational resolution for an almost weak pain state and includes more steps on the rational pain scale for stronger pain states, which matches the character of pain and the possibility for a valid assessment better than an ordinary visual analogue scale (VAS) (Borg, 1998).

[5] Segmental stabilisation means a special coordination pattern to involve deep trunk and lumbar back muscles. A slight tension of the pelvic floor, accompanied by a draw-in task for the belly button – submaximal activity of the musculus transversus abd. – and breathing slightly against the diaphragm is meant to increase the activity of deep back muscles, such as musculus multifidus. Using this coordination pattern, stability of lumbar vertebral segments and the transition to sacroiliac joints were found to be improved (Richardson, Hodges & Hides, 2004). Therefore, Segmental Stabilization Training is meant to represent that kind of specific exercise therapy, which was requested for the treatment of low back pain (Panjabi, 1992; Waddell et al. 1980).

All exercises were performed for one to three sets, with an intensity that allowed 10 to 15 repetitions or 20 to 30 seconds of static resistance, respectively. Number of sets and reps (volume and intensity and the choice of exercise itself (content) were determined by individual findings in the pre-test and anamnesis information right before starting the intervention. Training took place in the field of out-patient rehabilitation in groups of three to five patients and was conducted and controlled by at least one physiotherapist (Schröder & Färber, 2010).

3.6 Statistics

Data were described as mean ± standard deviation (SD), mean ± CI (95% confidence interval) for figure 4, and mean ± SEM (68% confidence interval meaning the Standard Error of the Mean) for figure 5. Normal distribution was proved using the Kolmogorov-Smirnov-test.

For the cross-sectional study, a factor analysis (SPSS 12: principle components extraction, Kaiser-normalisation with varimax rotation) was conducted to explore a spine shape structure model of almost independent factors, determined by video raster stereography spine shape parameters, seeking for differences between low back pain patients and pain free controls. In a second multivariate approach, discriminant analyses (SPSS 12) were calculated for males and females to reveal spine shape parameters being able to separate low back pain patients from pain free volunteers. At least, these extracted parameters were analysed for significant differences between patients and controls by means of univariate procedures (Student's t-test), and a spine shape profile was illustrated for males and females with or without low back pain.

For the analysis of treatment effects in the sample of patients who went through an exercise program, three-way ANOVAs (SPSS 12: within-subjects factor: pre vs. post exercise program, between-subjects factor for gender: female vs. male and between-subjects factor for age: under 60 years vs. over 60 years) were calculated. Bivariate Pearson correlations and linear multiple regression models based on pre-post-differences were calculated to analyse interdependencies of variables monitored in the process of reconditioning.

Significance was accepted for p-values of $p \leq 0{,}05$ *. Differences showing p-values of $p \leq 0{,}01$ ** or $p \leq 0{,}001$ *** were deemed very significant.

4. Results

4.1 Cross-sectional study

4.1.1 Factor analysis

A factor analysis revealed components describing almost independent spine shape characters determined by video raster stereography parameters, with respect to the interdependency of theses parameters. Different models for the controls (CON) and for the low back pain patients (LBP) indicated low back pain markers (tab. 3).

Trunk inclination (Tr-Inc), trunk imbalance (Tr-Imb), pelvis tilt (P-Tilt), pelvis torsion (P-Tors), thoracic kyphosis angle (KA-max), lumbar lordosis angle (LA-max), mean (root-mean-square) vertebral side deviation (Side-rms), and mean (root-mean-square) vertebral

	Components (CON) n=192				Components (LBP) n=213			
	1	2	3	4	1	2	3	4
Tr-Inc	**-0,673**	-0,083	-0,033	0,156	-0,189	-0,099	0,045	**0,756**
Tr-Imb	-0,031	0,065	0,046	**0,946**	-0,093	0,199	**0,759**	-0,067
P-Tilt	0,088	0,029	**0,829**	-0,070	0,131	0,217	-0,047	**0,700**
P-Tors	-0,148	-0,025	**0,758**	0,114	0,232	-0,138	**0,702**	0,068
KA-max	**0,721**	-0,098	-0,055	0,318	**0,798**	-0,034	0,191	0,049
LA-max	**0,739**	0,001	-0,055	-0,064	**0,861**	0,023	-0,067	-0,110
Rot-rms	0,220	**0,805**	0,130	0,010	-0,036	**0,768**	0,210	0,167
Side-rms	-0,199	**0,806**	-0,123	0,051	0,019	**0,833**	-0,118	-0,042

Table 3. Factor analysis – principle components extraction – for controls (CON: n=192) and low back pain patients (LBP: n=213) (factor loading coefficients over 0,65 printed in bold)

rotation (Rot-rms) served as variables (tab. 2). In the rotated component matrix, factor loading coefficients higher than 0,650 were enhanced to mark relevance (tab. 3). A factor analysis for the pain free controls revealed four components with an Eigen value greater than one, explaining 66% of the total variance. The table showed factor loading coefficients constituting independent factors for a summarizing description of human spinal alignment. Factors could be named as 'sagittal spine shape' (factor 1: LA-max 0,739 x KA-max 0,721 x Tr-Inc -0,673), 'vertebral deviations' (factor 2: Rot-rms 0,805 x Side-rms 0,806), 'pelvis parameters' (factor 3: P-Tilt 0,829 x P-Tors 0,758) and 'trunk deviation' (factor 4: Tr-Imb 0,946) (tab. 3). For low back pain patients, a component model of all four components explaining a total variance of 64,8 % could be revealed. In the first and most important component 'sagittal spine shape' the trunk inclination lost its influence (factor 1: LA-max 0,861 x KA-max 0,798). The second component 'vertebral deviations' did not differ from the controls (factor 2: Rot-rms 0,768 x Side-rms 0,833). Compared to the controls, there were some significant changes for the pelvis parameters. For low back pain patients, pelvis torsion was associated with trunk imbalance (factor 3: Tr-Imb 0,759 x P-Tors 0,702), and pelvis tilt was associated with trunk inclination (factor 4: Tr-Inc 0,756 x P-Tilt 0,700). So, the pelvis parameters were influencing the upper body position in the frontal and sagittal plane in back pain patients (tab. 3).

Summarizing the factor analyses, there were four independent components to describe spinal alignment for pain free persons: 'sagittal spine shape', 'vertebral deviations', 'pelvis parameters', and 'trunk deviation'. Low back pain was indicated by changes of the evidence of pelvis parameters compared to pain free controls. They were no longer an independent component, but were influencing the upper body position or deviation in low back pain patients.

4.1.2 Discriminant analysis

Discriminant analyses for male and female patients and controls included all spine shape parameters used before for the factor analysis.

For males, there was a relatively poor canonical correlation (eta^2 = 0,399), but the discriminant function led to a high significant solution for a group separation (Chi^2 = 32,810; $p \leq 0,001$; Wilks' Lambda = 0,841). For the males, there was a correctly predicted group membership of 70% using the discriminant function, 72% for the controls and 68% for the low back patients, respectively. Trunk imbalance offered the best capability to separate groups by means of the canonical discriminant function coefficients (Tr-Imb: 0,743) for males (tab. 4).

	Canonical discriminant coefficients	
	males (n=197)	females (n=208)
Tr-Inc	0,336	**0,610**
Tr-Imb	**0,743**	**0,441**
P-Tilt	0,157	0,006
P-Tors	0,066	**0,470**
KA-max	-0,146	-0,183
LA-max	-0,350	0,105
Rot-rms	-0,342	-0,374
Side-rms	0,067	0,340

Table 4. Canonical discriminant coefficients for males (controls n=113 and low back pain patients n=84) and females (controls n=79 and low back pain patients n=129) (relevant coefficients printed in bold)

For females, the canonical correlation was a little higher ($eta^2 = 0,448$; Wilks' Lambda = 0,799) than for males, and the discriminant function also led to a high significant solution for a group separation ($Chi^2 = 44,570$; $p \leq 0,001$). The prediction of correct group membership showed a ratio of 69%, 74% for the controls and 65% for the female low back patients, respectively. Trunk inclination and a little less trunk imbalance and pelvis torsion offered the best capability to separate groups by means of the canonical discriminant function coefficients for females (tab. 4).

Summarizing the results of the discriminant analyses, we found poor but acceptable discriminating functions for males and females, where group membership (LBP vs. CON) could be predicted correctly for approximately 70 % of all cases. Trunk imbalance in males and trunk imbalance with trunk inclination and pelvis torsion in females were the most appropriate spine shape variables to separate groups using a multivariate discriminant analysis function.

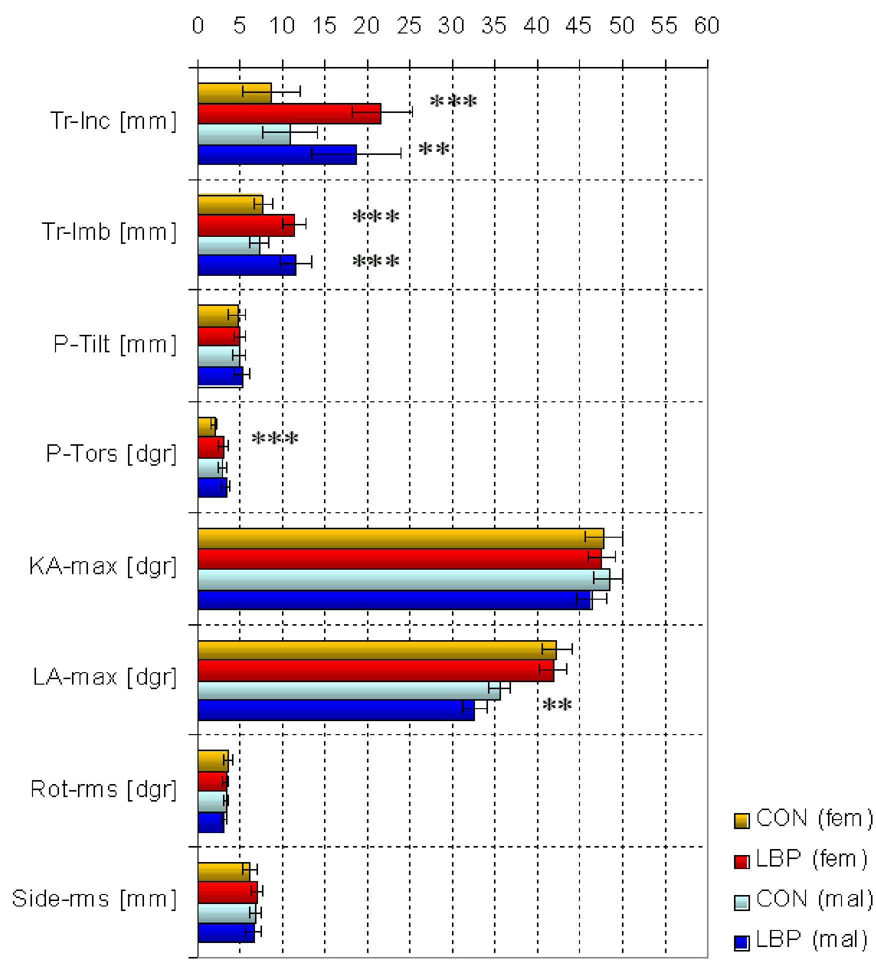
Evaluating both factor analysis and discriminant analysis, there were video raster stereography spine shape parameters that could be established to be associated with low back pain: trunk inclination and trunk imbalance with pelvis parameters mainly found in females, trunk inclination with trunk imbalance and the lumbar lordosis angle mainly found in males. Univariate analyses confirmed these multivariate findings.

4.1.3 Univariate analysis

Univariate comparisons revealed statistically significant mean differences between low back pain patients and controls for both men and women in their video raster stereography spinal alignment (tab. 5), illustrated as spine shape profiles (fig. 4).

	Tr-Inc [mm]	Tr-Imb [mm]	P-Tilt [mm]	P-Tors [dgr]	KA-max [dgr]	LA-max [dgr]	Rot-rms [dgr]	Side-rms [mm]
CON females	8,6	7,8	4,7	2,0	47,8	42,2	3,7	6,1
± SD	15,1	5,3	4,9	1,5	9,7	8,3	1,8	4,0
LBP females	21,6 ***	11,3 ***	4,9	3,1 ***	47,5	41,7	3,4	7,1
± SD	20,1	7,7	4,0	2,8	9,3	9,0	1,9	3,7
CON males	10,9	7,2	4,9	3,0	48,4	35,6	3,4	6,8
± SD	16,8	6,2	3,8	2,4	9,0	6,5	1,6	3,6
LBP males	18,7 *	11,6 ***	5,3	3,4	46,4	32,6 **	3,1	6,6
± SD	24,2	8,1	4,2	2,5	8,1	6,8	1,7	4,2

Table 5. Spine shape parameters for female and male controls vs. low back pain patients (Student's t-test: p≤0,05 *, p≤0,01 **, p≤0,001 ***)



(Mean ± 95% CI; Student's t-test: p≤0,05 *, p≤0,01 **, p≤0,001 ***)

Fig. 4. Video raster stereography spine shape profiles for males (light and dark blue: CON n=113 and LBP n=84) and females (light and dark red: CON n=79 and LBP n=129)

First of all, trunk inclination (Tr-Inc) (females' mean difference: 13,0 mm; t=-4,959; p≤0,001; males' mean difference: 7,8 mm; t=-2,534; p=0,012) and trunk imbalance (Tr-Imb) (females' mean difference: 3,6 mm; t=-3,993; p≤0,001; males' mean difference: 4,4 mm; t=-4,211; p≤0,001) differed significantly between low back pain patients and pain free controls. As for women, there was a significant difference in the parameter pelvis torsion (P-Tors) (mean difference: 1,2°; t=-3,811; p≤0,001), and for men in the parameter maximum lumbar lordosis angle (LA-max) (mean difference: 3,1°; t=3,204; p=0,002), respectively (tab. 5).

4.2 Effect analysis

The effect analysis dealt with changes in low back pain, trunk muscle function, and spinal alignment following a ten-week exercise program, where adaptations were assigned to a process called reconditioning. Effects were analysed using a three-way ANOVA to verify within-subjects effects and interactions with independent factors, like gender and age.

4.2.1 Parameters of low back pain reconditioning

Development of pain state (CR10) and trunk muscle peak forces following the exercise program were described as mean and standard deviation, and the within-subjects effect showed at least very significant increases of peak forces, and a decrease of pain, respectively. Trunk muscle torque was expressed as corresponding masses in kilogram for more transparency (tab. 6).

As for the low back pain state, there were neither significant differences between males and females (F=0,371; p=0,544) nor between younger and older patients (F=0,647; p=0,423) (between subjects factors), and there were no interactions for gender (F=2,910; p=0,091) or age (F=0,941; p=0,334) with the treatment effect, which in itself was very significant (F=60,603; p≤0,001) (within-subject factor) (tab. 6).

	CR10 [pts.]	Ext. [kg]	Flex. [kg]	Lat-lt. [kg]	Lat-rt. [kg]	Rot-lt [kg]	Rot-rt [kg]
LBP t1 total	3,8	56,7	30,5	29,4	29,7	30,6	32,1
± SD	2,3	25,7	17,0	11,8	12,5	16,1	15,3
LBP t2 total	2,3	69,9	35,7	34,3	34,1	36,5	38,0
± SD	1,8	28,8	17,3	13,5	13,7	19,6	19,5
Mean-diff.	-1,5 ***	+13,2 ***	+5,2 ***	+4,9 ***	+4,4 **	+5,9 ***	+5,9 ***
F=	60,603	30,563	16,969	16,727	9,280	17,515	23,426
p≤	0,001	0,001	0,001	0,001	0,003	0,001	0,001

Table 6. Pain (CR10 points) and trunk muscle peak forces for back extension (Ext), trunk flexion (Flex), lateral flexion to the right (Lat-rt) and to the left (Lat-lt), as well as axial rotation to the right (Rot-rt) and to the left (Rot-lt) before (t1) and after (t2) the exercise program for the total (n=107) of low back pain patients (within-subjects effect: p≤0,05 *, p≤0,01 **, p≤0,001 ***)

Of course, trunk muscle peak forces differed between males and females (extension: F=42,351; p≤0,001; flexion: F=23,482; p≤0,001; lateral-left: F=44,251; p≤0,001; lateral-right: F=33,686; p≤0,001; rotation-left: F=40,841; p≤0,001; rotation-right: F=47,507; p≤0,001), and also between younger and older patients (extension: F=7,745; p=0,006; flexion: F=21,945; p≤0,001; lateral-left: F=20,271; p≤0,001; lateral-right: F=6,923; p=0,010; rotation-left: F=7,821; p=0,006; rotation-right: F=4,441; p=0,038), but there were no significant interactions at all between grouping variables and the within-subjects factor (p>0,05), while the treatment effect itself was very significant in any dimension (extension: F=30,563; p≤0,001; flexion: F=16,969; p≤0,001; lateral-left: F=16,727; p≤0,001; lateral-right: F=9,280; p=0,003; rotation-left: F=17,515; p≤0,001; rotation-right: F=23,462; p≤0,001) (tab. 6).

With respect to references in the field of low back pain research, relative peak force increases were illustrated for both males and females separately (fig. 5). Relative increases ranged between approximately 20% to about 40%. Increases were higher in the back extension (approx. 35%) and trunk flexion (from about 30 to 45%) than in the lateral flexion (approx. 25%) and the axial rotation (from about 20 to 30%) (fig. 5).

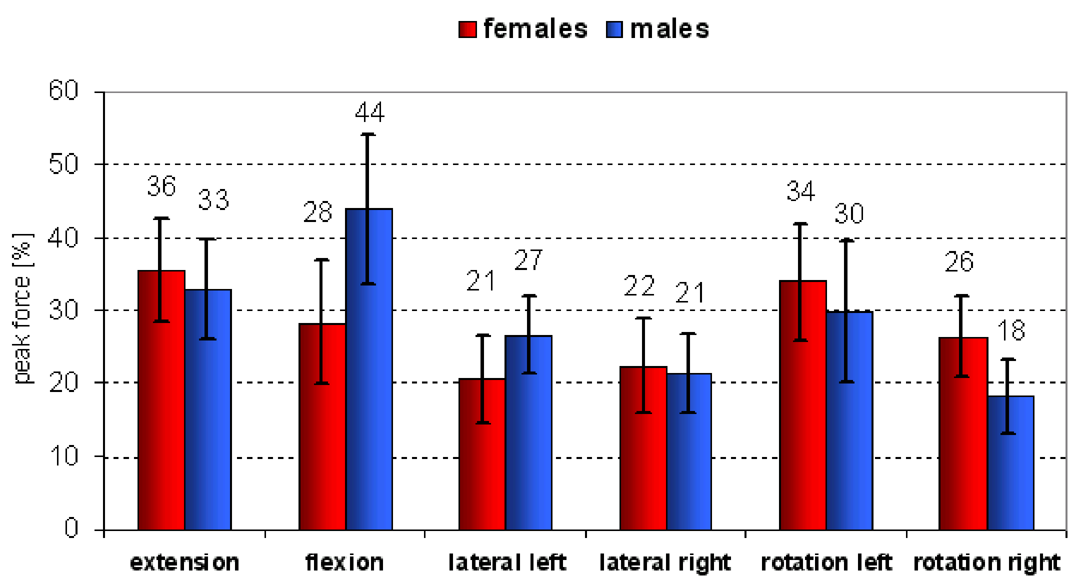


Fig. 5. Relative increases of trunk muscle peak forces for males (n=46) and females (n=61) (Mean±SEM)

Investigating the relation between clinical out-come and muscle function, multiple regression models for the estimation of low back pain decreases by means of relative peak force increases led to a multiple regression coefficient of R=0,292 (R^2=9%). The only predictor showing a tendency for a significant contribution to explain pain decrease was the relative increase of trunk flexion (β=0,216; p=0,055).

4.2.2 Parameters of spinal alignment

Three-way ANOVAs revealed significant within-subjects effects for only a few video raster stereography parameters of the spinal alignment. Pelvis torsion (P-Tors) and lumbar lordosis angle (LA-max) showed significant changes for the total of the low back pain patients – a group statistically verified – manifesting themselves in pelvis position correction

(-0,6°; F=5,145; p=0,025) and lumbar spinal erection (-0,7°; F=6,548; p=0,012), respectively (tab. 7).

	Tr-Inc [mm]	Tr-Imb [mm]	P-Tilt [mm]	P-Tors [dgr]	KA-max [dgr]	LA-max [dgr]	Rot-rms [dgr]	Side-rms [mm]
LBP t1 total	19,4	12,4	4,6	3,2	47,1	37,2	3,1	6,5
± SD	19,2	9,5	3,8	2,6	9,2	9,0	1,6	3,1
LBP t2 total	21,2	11,2	4,3	2,6	46,5	36,5	3,5	6,8
± SD	22,7	8,4	3,3	1,9	9,7	8,8	1,8	3,4
Mean-diff.	+1,8	-1,2	-0,3	-0,6 *	-0,6	-0,7 *	+0,4	+0,3
F=	2,122	1,671	2,524	5,145	1,698	6,548	3,029	0,131
p=	0,148	0,199	0,115	0,025	0,196	0,012	0,085	0,718

Table 7. Spine shape parameters before (t1) and after (t2) the exercise program for the total (n=107) of low back pain patients (within-subjects effect: p≤0,05 *, p≤0,01 **, p≤0,001 ***)

Changes in the sagittal plane were depending on gender (interaction: F=6,651; p=0,011), but not on age (interaction: F=2,596; p=0,110). Naturally, there were differences in the lumbar lordosis angle (LA-max) between males (t1: 31,6° ± 7,2°; t2: 31,8° ± 7,6°) and females (t1: 41,3° ± 8,0°; t2: 40,0° ± 8,0°) (between-subjects effect: F=25,305; p≤0,001), but there was no significant difference between younger and older patients (between-subjects effect: F=2,420; p=0,123).

Changes of pelvis torsion (P-Tors) were neither depending on gender (interaction: F=0,041; p=0,840) nor on age (interaction: F=0,582; p=0,447). There were no significant differences between males and females in the pelvis torsion (between-subjects effect: F=0,353; p=0,554), and also not between younger and older patients (between-subjects effect: F=0,642; p=0,425).

Differences from pre- to post-test for the total of the examined low back pain patients (n=107) in any other spine shape parameter did not reach significance levels (within-subjects effects: p>0,05) (tab. 7). And there were no significant between-subjects effects for gender (p>0,05) or age (p>0,05), except for the trunk inclination, where older people showed significantly larger values than younger persons (F=13,063; p≤0,001). Furthermore, there were no significant interactions between the within-subjects factor (treatment) and the between-subjects factors (gender and age), neither for trunk inclination (Tr-Inc), trunk imbalance (Tr-Imb), pelvis tilt (P-Tilt), and thoracic kyphosis angle (KA-max) nor for the vertebral side deviation (Side-rms) or the vertebral rotation (Rot-rms) (p>0,05).

Looking for specific adaptations of spinal alignment, bivariate correlations of alterations – maybe corrections – of spine shape parameters with extra-ordinary deviations (out-layers of the standard deviation interval before the start of the exercise program) in the frontal plane revealed significant correlation coefficients for trunk imbalance (r=0,40; p=0,021; n=33), pelvis tilt (r=0,43; p=0,038; n=23), and pelvis torsion (r=0,72; p≤0,001; n=26). There were no significant correlation coefficients for any other spine shape parameter, neither for the sagittal plane nor for the coronal plane, in this specific pre-post-analysis investigating parameter changes depending on the initial state prior to the exercise intervention.

Taking account of the alterations of spine shape parameters additional to the peak force increases, a linear multiple regression model explained the total variance of pain decrease (R=0,399; R^2=16%) better than using only peak force increases as predictors (R=0,292; R^2=9%). Only trunk imbalance contributed significantly as a predictor (β=0,248; p=0,036) to explain pain decrease.

5. Discussion

5.1 Cross-sectional findings

A literature review from the beginning of the 21st century did not come to a conclusive position of evidence (Bernard, 2002). Are there any correlations between posture or spinal mal-alignment and muscle function deficits connective with low back complaints? Univariate investigations – using video raster stereography or not – could not confirm these expectations (Heckmann et al., 2008; Nourbakhsh, Arabloo & Salavati, 2006). But in the field of physiotherapy or manipulative medicine and respective treatment as well as diagnostic procedures of low back pain (LBP) this assumption is considered to be a major guide line for therapy interventions (Lewit, 1991; Seeger et al., 1997).

There is some evidence for the relevance of psychosocial factors influencing the development and the progredience of low back pain. Furthermore, chronification and behavioral aspects of individual coping strategies could be established to be predictive factors for a treatment success (Hildebrandt et al., 1997). But with respect to organic signs, low back pain is considered to be unspecific. Pain is not assigned to structural correlates. Radiographic findings indicate the cause of low back pain only accidentally (Waddell et al., 1980). From an organic point of view, spinal instability seems to be a major risk factor, and probably might be a criterion for diagnosis procedures and therapy interventions (Panjabi, 1992).

According to this instability hypothesis, significant associations could be verified between low back pain and functional deficits of trunk muscle peak force (Cady et al., 1979; Denner, 1997; McNeill et al., 1980) and neuromuscular coordination patterns (Richardson, Hodges & Hides, 2004). Resulting deconditioning syndromes might not only be accompanied by functional disorders, but also by spinal mal-alignment and postural abberations (Müller, 1999).

Some epidemiological reviews or radiographic cross-sectional and follow-up studies extracted frontal plane asymmetries and a flatter lumbosacral transition as anthropometric risk factors for the development and progredience of low back pain (Adams, Mannion & Dolan, 1999; Balagué, Troussier & Salminen, 1999; During et al., 1985; Harrison et al., 1998; Masset, Piette & Malchaire, 1998; Nissinen et al., 1994).

As a main result, the present investigations could confirm these findings from the literature by means of multivariate analysis approaches and with the help of a non-invasive spine shape reconstruction device. Using video raster stereography, particular spine shape parameters were identified to be associated with low back pain (tab. 3 and tab. 4). Patients with chronic low back pain showed larger values for trunk imbalance (Tr-Imb: p<0,01) and trunk inclination (Tr-Inc: p<0,001) compared to pain free volunteers (tab. 5). Trunk inclination should be considered to be due to the higher age of the patients sample (Gelb et al., 1995; Kobayashi et al., 2004; Takeda et al., 2009), but trunk imbalance remained as an indicator variable to identify low back pain (Schröder, Stiller & Mattes, 2010; 2011). Additionally, female patients showed higher values in the parameter pelvis torsion (P-tors: $p<0{,}001$), and male patients had a flatter lumbar lordosis (LA-max: $p<0{,}01$), respectively (fig. 4) (Schröder, Strübing & Mattes, 2010). These findings were in a line with earlier studies based on radiological methods or mathematical models, respectively (During et al., 1985; Harrison et al., 1998).

Those recent results provide the idea that spinal mal-alignment should be associated with low back pain. Spine shape abberations might be one organic risk factor for the development of low back pain, but – on the other hand – it might also be a symptom of deconditioning processes in chronic low back complaints, as is well known for deficits of muscle function (Cady et al., 1979; Denner, 1997; 1999; McNeill et al., 1980).

5.2 Reconditioning and spinal alignment

Referring to systematic associations between spinal mal-alignment or aberrations of 'normal' spine shape and back complaints in chronic low back pain patients described above, we conducted a longitudinal study to analyse adaptations of an individualized exercise program. The exercise program was determinded by individual spine shape parameter findings, muscle function findings, and anamnestic data related to individual back complaints – comparable to programs based only on functional profiles of trunk muscle performance, evaluated earlier (Denner, 1997). Patients were meant to face individually composed tasks to generate almost individual adaptations – with an idea of treatment specificity.

In the present study, clinical outcome variables and muscular function parameters increased like they did in comparable studies using intensive muscle activation (Denner, 1999; Mannion et al., 2001a; 2001b; 2001c; Uhlig, 1999). Low back pain patients started the exercise therapy with a pain state of 3,8 (±2,3) points, in terms of Borg's CR10 scale meaning a back pain level from moderate to strong. Pain decreased to 2,3 (±1,8) points, meaning a pain level from very weak to moderate. These decreases were accompanied by peak force increases ranging from about 20% to approximately 40% (fig. 5), assigning that kind of reconditioning process described elsewhere for low back patients who went through an active rehabilitation program (Denner, 1997; 1999; Mannion et al., 2001a; 2001b; 2001c; Schröder et al., 2009). Multivariate analysis procedures seeking for a direct correlation between pain decrease and muscle function increases could not reveal significant coefficients (R=0, 292). These findings were in a line with earlier investigations, where a correlation coefficient of $r=0{,}20$ ($p=0{,}60$) could be established, which was also not suitable to support an assumption of a direct dependency between clinical out-come and muscle function state (Mannion et al., 2001b). Psychological factors, like awareness of increased muscle function and re-established self-confidence, were assumed to be reasonable mediators between decreases of pain or increases of health state parameters and increased muscle function and performance parameters (Mannion et al., 2001c).

Additionally, systematic and significant spine shape alterations – apparent in lumbar erection and correction of pelvis asymmetries – could be verified (tab. 7), comparable to earlier investigations (Schröder et al., 2009). With respect to the knowledge of interindividual spine shape variability and intra-individual variations in repeated measurements of spinal alignment (Jackson et al., 2000) known as 'margin error' in pre-post-analyses (Weiß, Dieckman & Gerner, 2003; Weiß & Klein, 2006) these small changes of pelvis torsion (P-tors: -0,6° ; p=0,025) and lumbar lordosis angle (LA-max: -0,7°; p=0,012) were interpreted as relevant and statistically significant effects, following an active exercise program based on individual findings and using specific treatment elements, like a reasonably high training intensity (Dalichau et al., 2005; Denner, 1997; 1999; Uhlig, 1999) and the special coordination patterns for deep trunk muscles known as Segmental Stabilization Training (Richardson, Hodges & Hides, 2004).

Unfortunately, the evidence of specificity of those exercise induced adaptations was still lacking. On the one hand, adaptations of spine shape parameters in the frontal plane (trunk imbalance, pelvis tilt, pelvis torsion) were greater the more abnormal these values were before the treatment (r=0,40 to 0,72; p≤0,05), but on the other hand, pain reduction could not be explained sufficiently, neither by increases of muscle function (R=0,292) nor by corrections of spinal mal-alignment (R=0,256), nor by the total of all parameters, muscle function and spinal alignment (R=0, 399).

Since correlations between clinical out-come variables and functional adaptations of trunk muscle peak force had rarely been investigated, correlations between pain decrease and alterations in the spinal alignment – with a focus on the monitoring of low back pain intervention and using video raster stereography – had as yet not been investigated anywhere else, apart from our own pilot study, where decreasing values of trunk imbalance were associated with pain decrease in those patients who showed sacroiliac symptoms (Schröder et al., 2009). Dalichau et al. (2005) used an ultra sound topometry device (Zebris®, Isny, Germany) to detect a thoracic erection following three modes of muscle activation exercise programs. Spinal erection was accompanied by trunk muscle peak force increases, adaptations in the performance of the Matthiass-Test (at the end of a 30-second test period) and pain decreases. Dalichau et al. (2005) found high correlation coefficients, but not directly between spine shape and peak force or pain changes. They correlated the degree of deviation of the thoracic kyphosis angle at the end of the Matthiass-Test with back pain intensity (r=0,91) and functional deficits (r=0,89). So, the results of Mannion and collaborates (2001b; 2001c), mentioned above, might serve as the only reference remaining for directly calculated correlations in a longitudinal study between peak force increases and pain decreases (r=0,20; p=0,60), but not taking into account exercise induced spine shape alterations.

6. Additional applications of spine shape analysis

Although the majority of all low back pain cases are of unknown etiology, new diagnosis procedures, such as video raster stereography, might be able to find structural or functional correlates of some specific origin for back pain complaints (McGill, 2007, p. 5).

For example, video raster stereography (Formetric®-system) is able to detect local changes of the convexity of the spinal curvature [6]. A sensitivity study of n=21 volunteers suffering from

[6] Kyphosis or lordosis describes an angle referring to geometric relations of the human anatomy, but there are changes of convexity also in the microstructure of the alignment of the spinous processes. If

accidental vertebral blockades provided the idea of automatically detectable structural deviations in the alignment of spinous processes in terms of overreaching the midline in the curve of the second mathematical differentiation of the lateral projection of the spine (fig. 6).

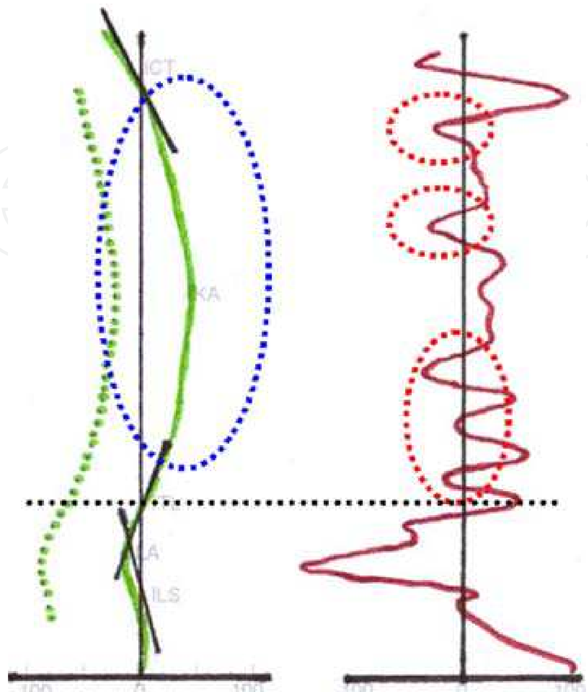


Fig. 6. Lateral projection of spinal alignment (left) with back surface (drawn green line) and calculated line of vertebral centres (dotted green line) with a focus on the thoracic spine (blue dotted oval) and the second mathematical differentiation (right) with the curve of local changes of angles at a given point (drawn red line) with an emphasis on curve areas reaching or overreaching the midline (red dotted ovals) indicating structural deviations in the normal spinal alignment of the thoracic spine (area above the black dotted line) (modified from Schröder, Stiller & Mattes, 2011, p. 165)

But video raster stereographic signals indicated signs for a vertebral blockade much more often than a manual examination by an expert did. Sensitivity of video raster stereography was almost poor (23%) (Schröder, Färber & Mattes, 2009; Schröder, Stiller & Mattes, 2011).

Furthermore, there was some evidence for the possibility to get helpful additional diagnostic information to identify sacroiliac joint (SIJ) pain origins in patients with single localized low back pain. Problems concerning the sacroiliac joints are supposed to be the cause for about 20% of all low back complaints, but diagnosis is difficult (Foley & Buschbacher, 2006). In a cross-sectional study, women with single localized low back pain corresponding to the area of sacroiliac joints (n=23) showed significantly higher values for trunk imbalance (mean-diff.: 4,9 mm; p≤0,001), for pelvis tilt (mean-diff.: 2,8 mm; p=0,007)

the direction of the curvature at a given segmental position changes completely from a right-sided convexity to a left-sided convexity, the curve of the second mathematical differentiation of the lateral projection of the spinal alignment reaches or overreaches the midline (fig. 6). Those changes of local convexity assign structural deviations of the normal spinal alignment, such as scoliosis curvatures or vertebral blockings.

and for pelvis torsion (mean-diff.: 1,1°; p=0,014) than pain free women (n=89). This was indicating deviations in the frontal plane like in low back pain patients, but enhancing the role of exceeded pelvis parameters. Maybe due to the normal differences between shape and geometry of male and female pelvis anatomy, these sacroiliac signs could not be confirmed statistically for male patients with comparable single localized pain (Schröder, Stiller & Mattes, 2011).

In the field of specific low back complaints, we could identify signals in the spinal alignment of the lumbar lordosis that referred to structural abberations of specific vertebral segments in low back pain patients suffering from a facet joint syndrome (fig. 7) (Schröder, Strübing & Mattes, 2010).

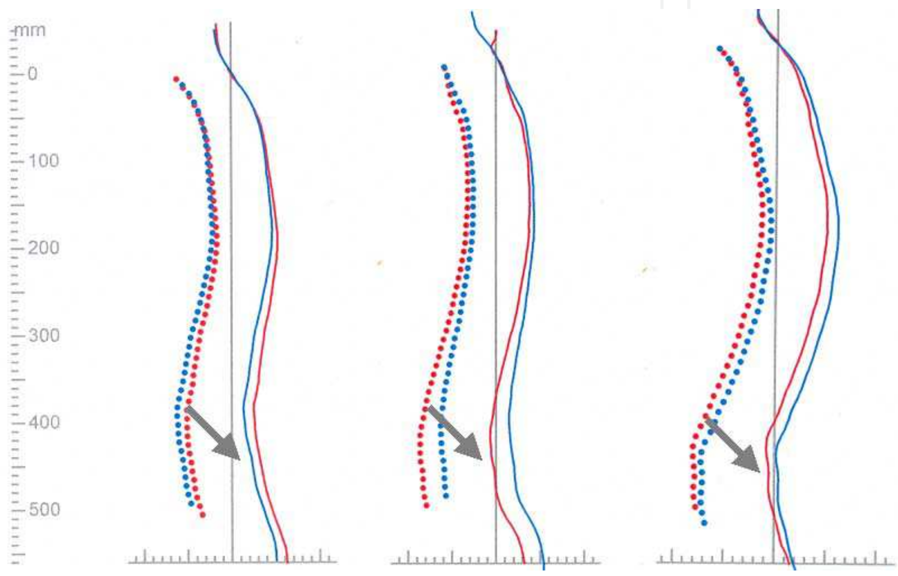


Fig. 7. Spinal alignment of three low back pain patients with different types of spine shape suffering from lumbar facet syndrome in repeated measurements (back surface [drawn] and calculated vertebral centres [dotted] before [red] and after [blue] treatment) with signals for structural changes of vertebral elements [arrows]

A functional diagnosis procedure to quantify leg length differences and to try out the best fitting correction had been evaluated earlier (Drerup et al., 2001). A functional test protocol for the quantification of spinal flexibility – especially for back extension limitations – by means of video raster stereography is currently performed (fig. 8), as the evidence of lumbar hypermobility or flexibility deficits is well known as a cause or a symptom of low back pain.

With regard to technical limitations of the high resolution Formetric®-system – anticipation of problems dealing with an automatic recognition of the vertebra prominens without manually fixed extra markers, while the upper body was hyperextended maximally and the camera was looking at it from above – the test protocol had to include three test positions. Data acquisition had been performed in a normal position, serving as a native reference to qualify the individual's spinal alignment. But pictures had also to be taken in a position with a forced hyper kyphosis as a basic reference for the following test position with the same artificial hyper kyphosis performed in a maximally extended spine position (fig. 8). Spinal flexibility for the backward hyperextension could be quantified in terms of changes of the lumbar lordosis angle, which was not affected by the artificial hyper kyphosis test position.

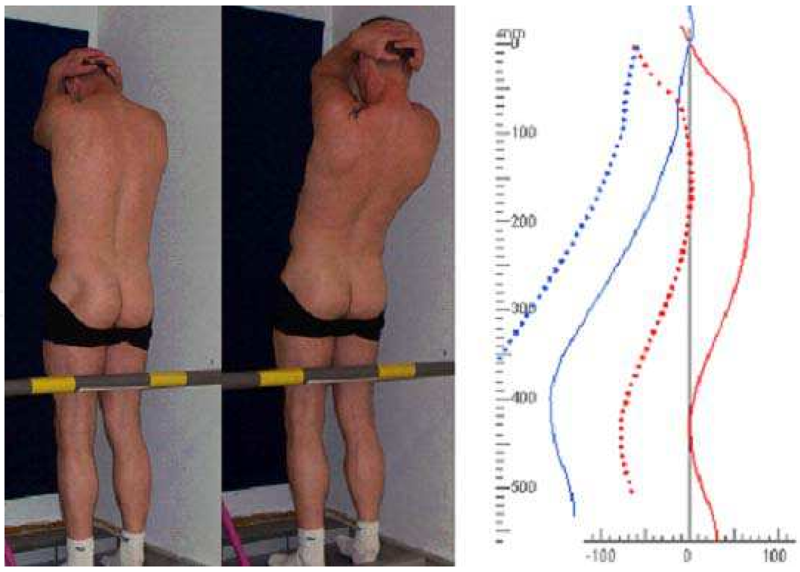


Fig. 8. Test position with artificial hyper kyphosis in a basic (left) and a maximally hyper-extended position (middle) and the video raster stereographic representation of spinal mobility (right) for the back extension task

7. Conclusion

A single cross-sectional study does not allow to draw any conclusions, whether spine shape alterations are the cause of low back pain or the symptoms following a process of deconditioning. But exercise induced adaptations of spinal alignment suggest the assumption that there is the possibility for a correction of mal-alignment. These alterations should be considered to be due to a functional restoration, comparable to increases of trunk muscle peak forces observed in the process of reconditioning.

Finally, the role of video raster stereography for quality management should be emphasized. The indirect and non-invasive assessment of the spinal curvature and pelvis position parameters offered valid, reliable and helpful information throughout the screening and monitoring processes for out-patient low back pain rehabilitation.

Further investigations, if possible with clustered samples of the degree of chronification or personal strategies of behavioral coping and – if possible – distinguished specific back pain complaints, are necessary to learn more about the role of spinal mal-alignment in patients with low back pain, and probably more about specific effects of different exercise treatment modes.

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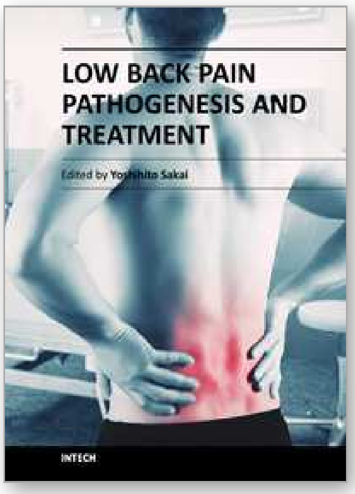

Low Back Pain Pathogenesis and Treatment

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Low back pain is a common disorder which affects the lumbar spine, and is associated with substantial morbidity for about 80% of the general population at some stages during their lives. Although low back pain usually is a self-limiting disorder that improves spontaneously over time, the etiology of low back pain is generally unknown and the diagnostic label, "non-specific low back pain", is frequently given. This book contains reviews and original articles with emphasis on pathogenesis and treatment of low back pain except for the rehabilitative aspect. Consisting of three sections, the first section of the book has a focus on pathogenesis of low back pain, while the second and third sections are on the treatment including conservative and surgical procedure, respectively.