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Reliability of Segmental Instability and Spinopelvic Alignment in Athletes with Isthmic Spondylolisthesis in Functional MRI

Reliabilität der segmentalen Instabilität und des spinopelvinen Alignments in Athleten mit isthmischer Spondylolisthesis im Funktions-MRT

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Summary

- **Problem Statement:** In athletes with spondylolisthesis, segmental instability and impaired spinopelvic alignment are considered as clinically relevant. Functional MRI in supine and upright position enables a load-dependent acquisition, but neither the reposition effect nor the difference in the extent of inter-position-related differences has been investigated for their reliability. This study evaluates the intra- and inter-positional test-retest reliability of segmental instability and spinopelvic alignment in athletes with low-grade isthmic lumbar spondylolisthesis using supine and upright MRI.
- **Methods:** 22 athletes with spondylolisthesis were analyzed in a test-retest design. Parameters quantifying segmental instability (anterior translation [mm], segmental hinging [°], disc height [mm]) and spinopelvic alignment (lordosis angle [°], Sacral slope [°]),) were assessed in supine (0°) and upright (82°) MRI position. Intra-positional changes and differences of inter-positional changes were analyzed using absolute and relative indicators of reliability (amongst other intraclass-correlation-coefficient (ICC 2.1) and standard error of measurements (SEM%)).
- **Results:** Intra-positional changes showed high correlations and low absolute changes in both positions (ICC: 0.91-0.98; SEM%: 1-7%). Differences of inter-positional changes presented poor-to-moderate correlations and higher absolute changes (ICC: 0.34-0.74; SEM%: 33-60%).
- **Discussion:** Intra-positional changes can be determined reliably among all assessed outcomes. Inter-position-related changes of segmental instability indicate a reduced reproducibility in the current population.
- **Conclusion:** Functional MRI can be considered a valuable diagnostic tool for evaluating segmental instability and spinopelvic alignment in spondylolisthesis patients.

Zusammenfassung

- **Problemstellung:** Bei Athleten mit Spondylolisthesis werden die segmentale Instabilität und das spinopelvine Alignment als klinisch relevant angesehen. Messungen im Funktions-MRT in liegender und stehender Position ermöglichen eine belastungs-abhängige Diagnostikmethode. Bislang wurde weder ein Repositionseffekt in beiden Positionen noch das Ausmaß der positionsbedingten Unterschiede auf ihre Reliabilität geprüft. Diese Studie untersucht die inter- und intra-positionsbedingte Reliabilität der segmentalen Instabilität und des spinopelvinen Alignments bei Athleten mit gering-gradiger lumbaler Spondylolisthesis mittels liegender und stehender MRT-Bildgebung.
- **Methodik:** 22 Athleten mit Spondylolisthesis wurden im Test-Retest-Design untersucht. Parameter der segmentalen Instabilität (anteriore Translation [mm], segmentales Aufklappen [°], Bandscheibenfachhöhe [mm]) und des spinopelvinen Alignments (Lordosewinkel [°], sakrale Angulation [°]) wurden in liegender (0°) und stehender (82°) MRT-Position analysiert. Intra-positionsbedingte Unterschiede und Differenzen der inter-positionsbedingten Unterschiede wurden hinsichtlich absoluter und relativer Reliabilitätsindikatoren (u. a. Intraclass-Korrelationskoeffizient (ICC 2.1) und Standardfehler der Messung (SEM%)) bewertet.
- **Ergebnisse:** Die intra-positionsbedingten Unterschiede zeigen hohe Korrelation und geringe Unterschiede der Absolutwerte in beiden Messpositionen (ICC: 0.91-0.98; SEM%: 1-7%). Differenzen der inter-positionsbedingten Unterschiede deuten auf schlechte bis moderate Korrelation mit hoher Änderung der Absolutwerte (ICC: 0.34-0.74; SEM%: 33-60%) hin.
- **Diskussion:** Intra-positionsbedingte Unterschiede können bei allen betrachteten Parametern reliabel bestimmt werden. Die Analyse der inter-positionsbedingten Unterschiede der segmentalen Instabilität impliziert eine reduzierte Reproduzierbarkeit in der betrachteten Population.
- **Schlussfolgerungen:** Das Funktions-MRT kann als sinnvolles diagnostisches Tool für die Bestimmung klinisch relevanter Messgrößen der segmentalen Instabilität und des spinopelvinen Alignments bei Patienten mit Spondylolisthesis eingesetzt werden.

KEY WORDS:
Reproducibility, MRI, Spinopelvic Balance, Repositioning, Functional Imaging

SCHLÜSSELWÖRTER:
Reproduzierbarkeit, MRT, spinopelvine Balance, Repositionierung, Funktionsdiagnostik

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Introduction

Lumbar spondylolisthesis is a common pathology among athletes, which potentially leads to load-dependent low back pain and segmental instability of the spine (3, 15, 19). Spondylolisthesis is characterized by a segmental slippage with an anterior translation of the cranial vertebral body in relation to the caudal vertebral body, usually classified by the Meyerding grading system (severity graded in mm of translation in relation to the length of the caudal endplate in%; grade I: 0 to 25%, grade II: 25 to 50%, grade

Table 1
Distribution of types of sports, sex, and severity of spondylolisthesis L5/S1.

TYPE OF SPORT	N	M/F	SPONDYLOLISTHESIS (MEYERDING GRADE 1 / GRADE 2)
All	22	12 / 10	13 / 9
Soccer	1	0 / 1	1 / 0
Track & Field	8	2 / 6	7 / 1
Wrestling	4	4 / 0	2 / 2
Judo	3	2 / 1	1 / 2
Canoe Racing	5	4 / 1	1 / 4
Horse Back Riding	1	0 / 1	1 / 0

III: 50 to 75%, grade IV: 75 to 100%, grade V: >100%) (14). Apart from the segmental anterior translation, it is also associated with alterations in the sagittal spinopelvic alignment, including the sagittal orientation of the lumbar lordosis and the sacrum in comparison to the horizontal plane (12, 13, 16). According to Wiltse et al. (1981), six different entities have to be distinguished, including isthmic spondylolisthesis (due to lysis, elongation of the pars interarticularis without fracture or acute fracture) being the most common in younger populations, and degenerative spondylolisthesis the most common in aging populations (2, 4, 5, 19). The average prevalence among athletes is 6.6%, with considerable differences between individual types of sports (17). The highest prevalence is found for low-grade spondylolisthesis between L5 and S1 (85% of cases), followed by L4/ L5 (10% of cases) (4). Depending on the severity and etiopathology, patients may exhibit diverse clinical symptoms including lumbar load-dependent back pain, ventralization pain, restricted mobility in reclination and rotation, and neurological symptoms (in high-grade spondylolisthesis).

For diagnostic assessment, standing x-ray is the gold standard, performed in two planes (anterior-posterior view and 45° oblique view) to measure the anterior translation of the vertebral body and detect possible discontinuities of the vertebral arch (pars interarticularis). More recently, the use of magnetic resonance imaging (MRI) has increased as a radiation-free alternative (1). As MRI is conventionally performed in the supine position, concern has been raised about the potential for misinterpretation of the extent of load-dependent parameters. Standing, weight-bearing images in functional MRI could resemble the characteristics and conditions of standing radiographs and thus provide valid results. In addition, surrounding structures (e. g. ligamentous and cartilaginous structures) can also be imaged, which cannot be properly assessed by x-ray.

Upright MRI procedures have been shown to be of clinical value in the detection of load-dependent changes in parameters indicating spondylolisthesis and segmental spine instability (11). An investigation by Hansen et al. (2015) determined moderate to excellent correlation of inter- and intra-rater comparisons between supine and upright MRI position of lumbar degenerative spine pathologies, including degenerative spondylolisthesis, in n=56 adult patients with low back pain (6). However, the reliability of upright MRI measurements defining segmental instability and spinopelvic alignment in an athletic population with isthmic low-grade spondylolisthesis L5/S1 hasn't been clarified conclusively (3). It is unclear, whether potential changes in parameters defining segmental instability can be reliably detected between supine and upright position in a test-retest situation (3). Therefore, this study aims to evaluate the intra-positional test-retest reliability of both, supine and upright MRI of parameters quantifying segmental instability and spinopelvic alignment in athletes with low-grade isthmic lumbar spondylolisthesis. Furthermore, the inter-positional reproducibility of the delta change in segmental instability parameters between the positions is analyzed.

Material and Methods

In a test-retest design (M1 and M2), 22 young athletes (overall: 19±4 years, 172±8 cm, 66±13 kg; male (n=12): 20±5 years, 174±9 cm, 71±15 kg; female (n=10): 17±3 years, 171±5 cm, 59±6 kg) with radiographically confirmed low-grade isthmic lumbar spondylolisthesis at level L5/S1 (grade I or II according to Meyerding classification, with and without low back pain) from different sports were included (table 1). The participants were recruited from the patient database (year 2012 to 2022) of a university outpatient clinic, which provides preparticipation examination and sports medicine care for all athletes prior to and during their attendance of a sports school in the federal state. Participants who were either unable to stand still for 10 min or had an acute infection, metal implant, or copper IUD (Intrauterine device) were excluded. The study was approved by the local Ethics Committee of the university and followed the guidelines for the conduct of clinical studies by the Declaration of Helsinki. Participants and legal guardians gave written informed consent to participate in the study.

Measurement Protocol

Sagittal and transversal T2-weighted fast spin echo scans (FSE; time to echo: 125 ms, slice thickness: 4 mm, flip angle: 90°, time to repetition: >2200 ms) were acquired in an open low-field MRI (0.25 Tesla, Esaote G-Scan, Italy). Data acquisition started in upright (82° inclination, loaded, fixation on pelvis and shoulder girdle with safety straps) and then was followed directly by the supine position (0° inclination, unloaded), as previously described in a pilot study (3). The field of view ranged from the intervertebral space of the 12th thoracic vertebrae and first lumbar vertebrae (S1) to the spinopelvic junction (complete imaging of superior endplates of S1 and of the sacrum was required). The same measurement protocol was repeated at both measurement time points, M1 and M2. Between both measurements the participants left the device for at least 10 minutes before repositioning and conduction of the second measurement.

Data Processing

Based on the sagittal T2 scans, segmental instability was quantified using the anterior translation of the affected segment L5/S1 (AT, distance between tangent placed on posterior margin of L5 and superior endplate of S1 [mm]), the lumbosacral joint angle (LSJA; angle between the cranial endplate of S1 and the caudal endplate of L5 [°]), and the intervertebral distance height L5/S1 (IVDH; mean value of the distance between the cranial cover plate S1 and the caudal cover plate of L5, measured at 3 intersegmental positions: anterior, middle, posterior; [mm]). Spinopelvic alignment was evaluated by lumbar lordosis (LL, angle between cranial endplate S1 and cranial endplate L1 [°]), and sacral slope (SS, angle between superior endplate of S1 and the horizontal [°]). An illustration of the parameter determination can be found in figure 1 A to E. Parameters were evaluated once in each image by the same investigator using a medical imaging software (Lara Pro).

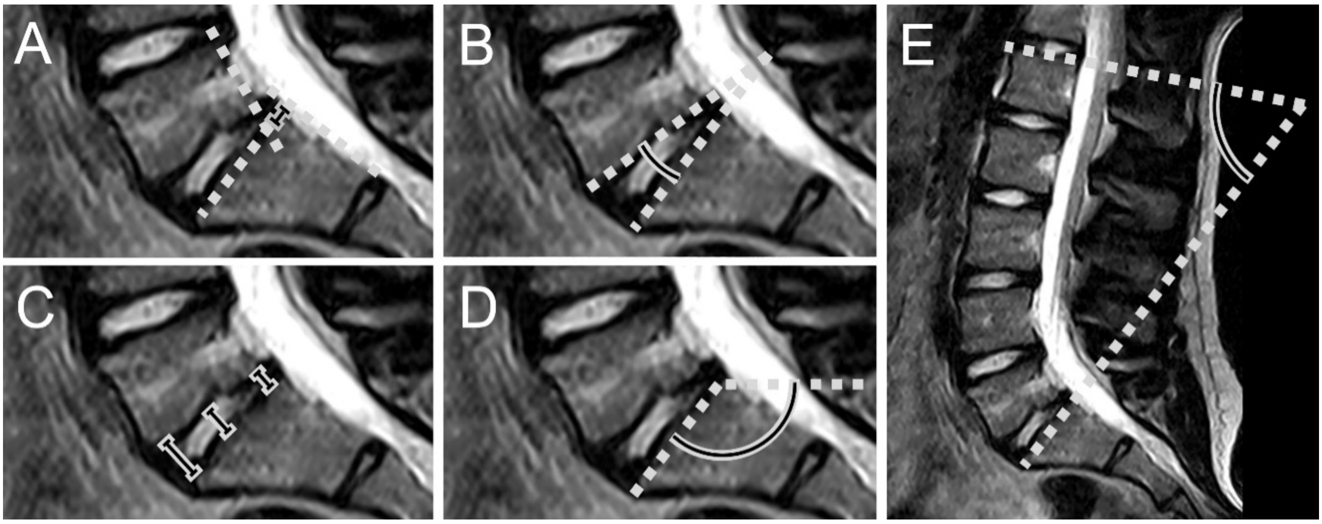

Figure 1

Assessment of parameters (A=AT [mm]; B=LSJA [°]; C=IVDH [mm]; D=SS [°]; E=LL [°]). Abbreviations explained in Data Processing.

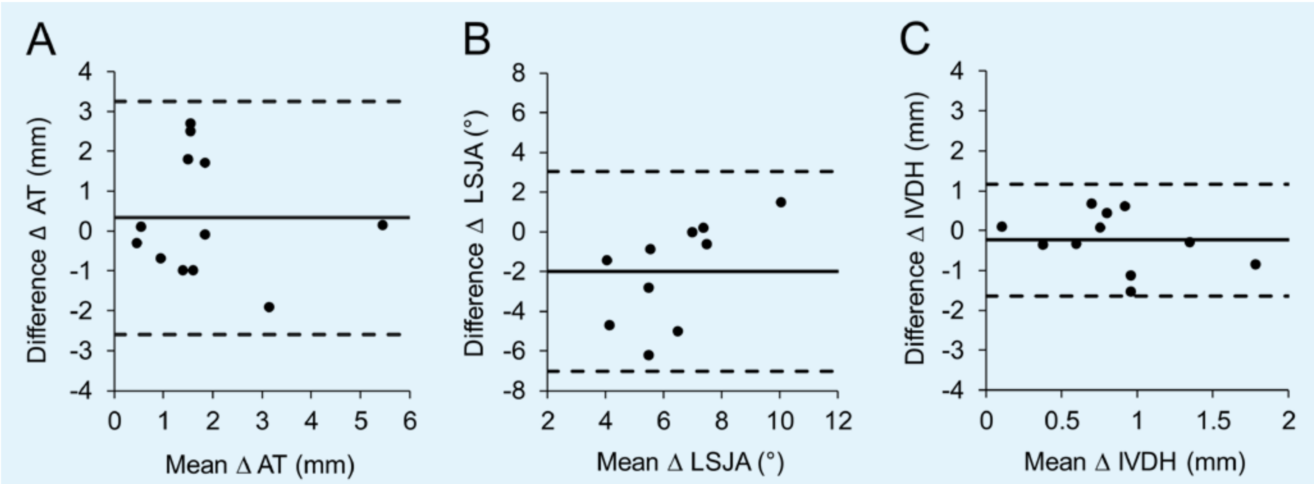

Figure 2

Bland-Altman plot of A=Δ AT [mm] between M1 vs. M2; B=Δ LSJA [°] between M1 vs. M2; and C=Δ IVDH [mm] between M1 vs. M2.

Statistical Analysis

Data analysis was performed descriptively by providing mean and standard deviation (SD) for all parameters at both time points M1 and M2 in both upright and supine position as well as for the delta change between both conditions. Reposition effect was discriminated for (I) intra-positional (0° vs. 0° and 82° vs. 82°; AT, LSJA, IVDH, LL, SS) and (II) inter-positional changes (shift from 0° to 82° of M1 and M2; AT, LSJA, IVDH). Test-retest reliability of the measurement procedure was analyzed by the intraclass-correlation-coefficient (ICC 2.1), the standard error of measurement (SEM, SEM%, SDDifference*√(1-ICC))*100 for percentage, as well as the Bland Altman analysis (Bias with upper and lower limits of agreement (bias±1.96*SD, upper Limits of agreement (uLoA), lower Limits of agreement (lLoA)) for all parameters at both measuring conditions. ICC results were interpreted based on the recommendations by Koo and Li (2015): <0.5 poor, 0.5 to 0.75 moderate, 0.75 to 0.9 good, >0.9 excellent (10).

Results

In supine position, all n = 22 images of included participants could be analyzed, while in upright position, n=12 measurement could be acquired and analyzed. Reasons for exclusion of upright scans were image availability (e.g. early termination due to dizziness) or insufficient image quality.

Analysis of Intra-Positional Reliability

Parameters indicating the segmental instability and spinopelvic alignment showed slightly higher correlations as well as lower values of data variability in supine (ICC: 0.92-0.98; SEM%: 1-2%) compared to upright position (ICC: 0.91-0.94; SEM%: 2-7%). The AT ranged from 2.8 to 13.3 mm in supine position and from 3.9 to 12.8 mm in upright position. The LSJA varied from 3.2 to 23.3° in supine position, and from 1.5 to 15.2° in upright position, while the IVDH varied from 4.9 to 12.5 mm and from 5.3 to 9.7 mm, respectively. The LL ranged from 29.0 to 73.2° in supine position, and from 28.1 to 77.0° in upright position, while the SS varied between 26.9 and 59.7° to 27.3 and 55.0°, respectively. Further details, as well as the results of relative and absolute reliability indicators for both measurement conditions (0° and 82°) are presented in table 2.

Analysis of Inter-Positional Changes of Segmental Instability Parameters

The inter-positional delta changes from supine to upright position of AT were at M1 in mean 1.1 mm with a range from ›

Table 2

Differences between M1 and M2 in 0° and 82° (absolute values, mean±SD) and results of intra-positional reliability. ICC=Interclass coefficient; SEM=Standard error of measurement; lLoA=lower Limits of Agreement; uLoA=upper Limits of Agreement, SD=Standard deviation.

CONDITION	TEST	AT	LSJA	IVDH	LL	SS
0° M1		7.1±2.5 mm	15.5±4.5°	8.6±0.8 mm	58.7±4.0°	46.4±3.7°
0° M2		7.0±2.4 mm	14.5±4.8°	8.4±1.5 mm	57.4±3.3°	45.9±2.2°
82° M1		8.6±2.7 mm	8.6±4.3°	8.1±0.8 mm	64.3±5.8°	47.5±5.4°
82° M2		8.2±2.3 mm	9.3±4.9°	7.9±1.1 mm	63.7±5.5°	46.5±2.8°
0°	ICC	0.98	0.96	0.97	0.92	0.94
	SEM	0.1 mm	0.3°	0.1 mm	1.2°	0.8°
	SEM %	2	2	1	2	2
	BIAS	0.6 mm	0.6°	-0.2 mm	-0.7°	-0.8°
	lLoA	-1.6 mm	-3.3°	-1.4 mm	-10.5°	-6.9°
	uLoA	2.1 mm	2.1°	1.0 mm	9.1°	5.3°
82°	ICC	0.91	0.93	0.91	0.94	0.93
	SEM	0.5 mm	0.5°	0.2 mm	1.3°	1.0°
	SEM %	6	7	3	2	2
	BIAS	0.5 mm	0.9°	0.1 mm	0.4°	-0.4°
	lLoA	-2.6 mm	-3.1°	-1.9 mm	-9.8°	-7.6°
	iLoA	3.5 mm	4.8°	2.2 mm	10.6°	6.7°

-0.6 to 5.4 mm, and at M2 in mean 1.3 mm with a range from -2.9 to 5.5 mm, with a corresponding SEM of 0.8 mm. The LSJA showed mean delta changes at M1 of -5.0° with a range from -9.3 to -4.8°, and at M2 of -7.3 mm with a range from -10.8 to -1.8°, with a corresponding SEM of 2.1°. The IVDH mean difference of delta change at M1 was 0.8 mm with a range from -2.2 to -0.1 mm, and 0.8 mm with a range from -1.4 to -0.2 mm at M2, with a corresponding SEM of 0.5 mm. Parameters of relative and absolute reliability were rated as moderate for AT and as poor for LSJA and IVDH (ICC: 0.34 to 0.74; SEM%: 33-60%). More detailed results on inter-positional changes are presented in table 3. Additionally, Bland-Altman plots of the AT, LSJA and IVDH are shown in figure 2 (A-C).

Discussion

The study aimed to evaluate the intra- and inter-positional test-retest reliability of supine and upright MRI using parameters quantifying segmental instability and spinopelvic alignment in young athletes with low-grade lumbar isthmic spondylolisthesis. The results of the study indicate high intra-positional reliability (ICC >0.90, SEM%=1 to 7%) of supine and upright measurement positions. In contrast, only poor-to-moderate inter-positional reliability regarding parameters defining segmental instability (ICC=0.34 to 0.71, SEM%=33 to 60%) can be detected between supine and upright position in a test-retest situation in athletes with low-grade spondylolisthesis.

Intra-Positional Analysis

To our knowledge, this is the first study to investigate the repositioning effect in a test-retest design in athletes with isthmic low-grade spondylolisthesis in supine and upright position using MRI diagnostics. An investigation by Hansen et al. (2018) determined the inter- and intra-rater reliability in various MRI positions of lumbar degenerative spine pathologies, including spondylolisthesis, in adult patients with low back pain. Participants were measured once in upright followed by supine position. Data was re-evaluated twice by three observers. The results showed moderate to excellent inter-rater (n=56; inter-rater k=0.71 (CI: 0.64 to 0.76)), and intra-rater reliability (n=20; intra-rater k=0.85 (CI: 0.77 to 0.90)) in upright imaging (6). The results of the present study are in line with findings of Hansen et al. (2018), though being assessed in an athletic population, and incorporating repositioning of the participants between the two measurements.

Compared with the supine position, upright measurements enable similar high to excellent reproducibility in assessing parameters of segmental instability and spinopelvic alignment Likewise, a study by Hioki et al. (2011) saw comparable data in measuring sagittal lumbar configuration and spinopelvic alignment in unloaded (supine) and loaded (supine with axial compression via footplate and fixation on shoulder girdle, 50% of individual bodyweight) position by use of computed tomography. In a test-retest-study, they assessed the lumbar spine among n=14 healthy asymptomatic participants (age ranging from 21 to 32 years). Their results also showed good to excellent reproducibility in both measuring conditions of LSJA, LL, SS, and IVDH (supine: ICCLSJA=0.97, ICCLL=0.99, ICCSS=0.99, ICCIVDH=0.95; supine + axial loading: ICCLSJA=0.92, ICCLL = 0.91, ICCSS=0.97, ICCIVDH=0.87). However, anterior translation and absolute reliability were not investigated in this study (7).

Comparing the reliability between two positions, the results of the present study show an increased systematic measurement error of parameters indicating segmental instability (AT, LSJA, IVDH) in upright MRI testing (supine: SEM%=1 to 2%, upright: SEM%=3 to 6%). Reasons could lay in the reduced resolution and image quality of the MRI scans in upright position due to shortened scan time and increased motion artifacts.

Inter-Positional Analysis

Although intra-positional analysis reveals high reliability for repeated measurements, the difference between the conditions (supine to upright) after repositioning shows only poor-to-moderate agreement for the measured parameters of segmental instability. Furthermore, data of absolute reliability indicate relatively high variations between the conditions, e. g. the

Table 3

Inter-positional differences (0°-82°) at M1 and M2 (absolute values, mean±SD) and relative and absolute reliability parameters of inter-positional differences for M1 vs. M2.

COND.	TEST	AT	LSJA	IVDH
M1 Δ 0°-82°		1.3±1.9 mm	-7.3±1.4 °	0.8±0.9 mm
M2 Δ 0°-82°		1.1±2.3 mm	-5.0±3.4 °	0.8±0.7 mm
M1 vs. M2 Δ 0°-82°	ICC	0.71	0.34	0.49
	SEM	0.8 mm	2.1 °	0.5 mm
	SEM %	44	33	60
	BIAS	0.3 mm	-2.0°	-0.2 mm
	lLoA	-2.6 mm	-7.0°	-1.6 mm
	uLoA	3.3 mm	3.0°	1.2 mm

SEM% that ranges from 33% (for LSJA) to 60% (for IVDH). It has to be taken into account that the SEM depends largely on the standard deviation of the individual values and is also affected by elevated intra-position variability. The above-mentioned investigation of Hansen et al. (2018) draws a similar picture, presenting a low inter-rater reliability of inter-positional changes (k=0.34 (CI: 0.30 to 0.38) between supine and upright condition. However, in their investigation only the agreement of the presence of inter-positional differences between supine and upright measurements and not the values of individual parameters were assessed (6).

The evaluation of position-related factors influencing the variability and the magnitude of segmental parameters in comparison of supine to upright measurements should therefore be considered individually in the clinical context and investigated in further studies. With respect to the population screened, general conclusions of position-related differences between both measurement positions should be evaluated with caution. Furthermore, the influence of positional pain, could have affected the individual positioning of the pelvis and lumbar spine in upright position between measurements. In this regard, Cassel et al. 2015 investigated the effect of inter-positional changes on parameters indicating segmental instability in relation to lumbar back pain in n=22 adolescent athletes with spondylolisthesis using an identical measurement protocol as used in the current study. They demonstrated statistically significant mean differences of 1.4 mm in anterior translation between both positions (3). However, reflecting the high variability of inter-positional changes detected in the present study, clinical significance has to be questioned.

Also, the overall small magnitude of position-related delta changes of the assessed parameters in the present study might be critical regarding technical restrictions and observers' precision. Furthermore, it should be emphasized that only differences of AT of >3mm can be interpreted as clinically relevant (8). To reduce the variability of assessed outcomes averaging repeated individual measurements might be a suitable approach (18). However, this study focused on clinical applicability. And it can be assumed that this approach might be impractical in the clinical context.

Clinical Application

In regular practice, diagnostic imaging using upright x-ray provides evidence of ventral displacement in a single plane with radiation exposure. Diagnostics by MRI enables however, multidimensional and radiation-free imaging of bony structures as well as cartilaginous and ligamentous surrounding structures. However, from an economic and practical point of view, it should be emphasized that the use of an MRI is associated with increased costs and a longer acquisition time compared to an x-ray. Likewise, access to a suitable device (especially a functional MRI) could be a significant barrier.

Due to a lack of evidence a comparison between upright MRI diagnostics and upright x-ray could only be evaluated to a limited extent. Only one study by Kanno et al. (2015) investigated the reliability of the extent of the spondylolisthesis in upright radiographs compared to supine MRI images as well as with additional axial compression in n=43 patients with degenerative lumbar spondylolisthesis. The ICC between the radiograph and conventional, supine MRI was ICC=0.40. In contrast, the agreement between radiographs and supine MRI with axial compression was significantly higher (ICC=0.75) (9). A comparison of the extent of segmental instability and spinopelvic alignment between upright radiographs and upright MRI scans should be investigated in future studies.

Limitations

The small sample size and reduced number of analyzed data in standing measurements (n=12) could affect the generalizability of the presented results. In addition, technical conditions of the MRI device (0, 25 T) and potential motion artifacts especially during upright imaging could potentially affect the evaluation of the parameters by reduced image quality. The exclusion of n=10 upright measurements, which were severely degraded in quality due to motion artifacts, was essential to ensure the validity of the results. Though participants were fixated at both the pelvis and the shoulder girdle in a standardized manner. The exact repositioning of the pelvic and lumbar spine positioning could not be fully guaranteed. Image quality was likewise reduced by a shortened measurement time during upright imaging. As in other studies with a similar measurement protocol, the risk for a vasovagal decrease in blood pressure, thus dizziness and possible fainting has been shown to be reduced by keeping the standing time as short as possible at the beginning of the measurement procedure (3, 6). Therefore, the risk of aborting the measurements and harming the health of the participants is minimized. Lastly, the presence of load-depended pain and thus a possible influence on the body positioning during the measurement was not investigated and should be included in future studies.

Conclusion

Segmental instability and spinopelvic alignment can be reliably assessed in supine and upright position showing a small difference after repositioning in athletes with low-grade › isthmic spondylolisthesis. The intra-positional differences are more difficult to reproduce in repeated measurements, which could be attributed to low absolute values. It should be emphasized that positional differences from supine to upright measurements are only detectable and clinically relevant above a threshold of 3 mm for the anterior translation. In order to reduce radiance exposure, functional, upright MRI is recommended to be used for diagnostic imaging, especially in cases of position-dependent changes of symptoms and suspected co-morbidity of surrounding structures.

To Sum Up

- The assessment of segmental instability and spinopelvic alignment is reliable in both, supine and upright position after repositioning
- Since segmental instability and spinopelvic alignment differ only slightly between positions, limits of clinical relevance should be taken into account when evaluating the results of individual parameters in athletes with isthmic spondylolisthesis.
- Poor-to-moderate inter-positional reliability of parameters quantifying segmental instability indicates its clinical application with caution.
- Functional, upright MRI is useful diagnostic method determining load-depended changes of in patients with spondylolisthesis

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Conflict of Interest

The authors have no conflict of interest.

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