# KINEMATICS OF THE TRUNK AND THE SPINE DURING UNRESTRICTED AND RESTRICTED SQUATS – A PRELIMINARY ANALYSIS

**Renate List, Turgut Gülay, Silvio Lorenzetti**

**Institute for Biomechanics, ETH Zurich, Switzerland**

The aim of the study was the assessment and comparison of trunk kinematics during restricted (knee not beyond toes) and unrestricted squats. Eight repetitions of restricted and unrestricted squats with 0, 25% and 50% bodyweight loading using a barbell were assessed with a 12 camera motion analysis system. A trunk marker set was developed and applied that allowed the measurement of the 3D kinematics of the trunk, divided into three segments (lumbar, thoracic and upper trunk) and the analysis of the sagittal curvature (lumbar and thoracic spine). The preliminary results of four subjects showed a larger range of sagittal motion between lumbar and pelvic segments for the restricted compared to the unrestricted squat. The lumbar curvature straightened with increasing load. The unrestricted execution seems to lead to higher stresses in the lower back.

**KEYWORDS:** squat, marker set, trunk, back, kinematics

**INTRODUCTION:** The squat exercise is one of the basics in fitness training, in strength training and in rehabilitation. In the bfu report 39 (bfu: Swiss Federal Office for Accident Prevention) the squat exercise was evaluated as one of the most predestinated exercises for injury-risk and complaint-risk (Müller, 1999). The squat can be performed in a restricted (**r**) and in an unrestricted (**unr**) type. In the **r** type the knees are only allowed to move until they reach the vertical line of the toes. The **r** type of the exercise is very often used in fitness centers (Chandler and Stone, 1991). However, it is unclear what effect the restriction of displacement in the lower limbs has on the kinematics of the trunk.
Most of the current trunk models based on skin marker assessment either consider the trunk as a single segment (Ferrarin et al., 2005; Kramers-de Quervain et al., 2004; Nguyen and Baker, 2004; Whittle and Levine, 1997) or describe spine motion (D'Amico et al., 1995; Frigo et al., 2003; Whittle and Levine, 1997). Crosbie et al. (1997) divided the trunk into three segments, namely lumbar, lower trunk and upper trunk, each defined by three skin markers allowing to describe three dimensional segmental kinematics. Compared to the huge range of different marker sets to assess the kinematics of the lower extremities, only very little work has been done concerning the trunk.
The kinematic investigation of the different types of the squat exercise is important for the strategy of appropriate strength training (Lorenzetti et al., 2009). Thus, the aim of the present study was to compare trunk motion between **r** and **unr** squats. This included the development of a suitable trunk marker set and its kinematic procedure to assess the kinematics of the trunk during squats based on skin markers.

**METHOD:** Twelve subjects, all movement science students experienced in weight lifting participated in this study. Four subjects were preliminary analysed. In average the four subjects weighed 67.5 ± 15.5 kg, showed a height of 175 ± 14 cm and an age of 24 ± 5 years.
The 3D motion analysis system used is a 12 camera VICON MX system (Oxford Metrics Group, UK). The used capture frequency was 50 Hz and the capture volume 300 cm x 500 cm x 200 cm. The used marker set for the assessment of trunk and pelvis kinematics consisting of 31 skin markers with a diameter of 9 and 14 mm is shown in Figure 1 and Table 1. The allocation of the markers to the used segments is shown in Table 2.
First, the subjects had to perform a standing trial in an anatomic upright position. Following, the subjects performed **r** and **unr** squats with zero, 25% bodyweight (BW) and 50% BW loading using a barbell. Each of the six conditions consisted of eight repetitions. For the **r** squat, the knee was not allowed to go beyond the toes. This restriction was visually self-controlled by the subject with the use of a live projection of the side view of knee and toes

and a pile marking the front edge of the toes onto a screen in front of the subject. No external force was applied to restrict the motion of the knee. The **unr** squat was performed with no restriction on the motion of the knee.

Two approaches were used to describe the kinematics of the trunk, a segmental and a curvature approach.

*Segmental approach:* The position and orientation of each segment was determined relative to the reference segments defined by the standing trial using a least-squares fit of the corresponding marker point clouds (Gander and Hrebicek, 1997). It follows that the neutral position (0° rotation) was defined by the standing trial. Each segment was defined by a redundant number of markers, aiming in an improvement in orientation accuracy (Challis, 1995). Joint rotations were described from the lower relative to the upper segment (pelvic relative to lumbar, lumbar relative to thoracic and thoracic relative to upper trunk segment) using a helical axis approach (Woltring, 1994). To define clinically interpretable rotational components the attitude vector was decomposed along the axes of a marker based joint coordinate system (Woltring, 1994). The vertical axis $e_v$ of the joint coordinate system, connecting line between the spine markers L5 and C7, is the leading axis, pointing cranial. The transverse axis $e_t$ is perpendicular to $e_v$ and lies in the plane spanned by $e_v$ and the connecting line between the markers RTBL and LTBL, pointing from left to right. The posteroanterior axis $e_{pa}$ is perpendicular to the latter two and points to the front. Hence, clinical rotations are described as follows: rotation around $e_v$ stands for axial rotation (positive rotation denotes a frontal motion of the left upper segment with respect to the lower), around $e_t$ for flexion/extension (positive rotation corresponds to forward flexion) and around $e_{pa}$ for lateral bending (positive rotation stands for bending to the left side).

For the assessment of the sagittal plane curvature of the lumbar and the thoracic spine, the corresponding marker positions were projected on to the sagittal trunk plane defined by the plane spanned by $e_v$ and $e_t$. The curvature was estimated by the reciprocal of the radius of the circle that was fitted into the corresponding five markers using a least-squares approach.

A squat cycle was defined as starting in a more or less upright position, moving down to the lowest position and up again. The start and end point of the cycle was defined by the vertical velocity of the barbell ($v_{barb}$ > 0.02m/s). For each condition mean and standard deviation (SD) over the eight repeated cycles were calculated.

ROM was defined as the range between minimal and maximal reached rotation values.

**Table 1: Marker placement and abbreviations.**

| | |
|---|---|
| RTSH, LTSH | right and left acromion |
| RTCL, LTCL | right and left clavicle |
| STER | sternum |
| RTSC, LTSC | right and left inferior angle of the scapula |
| RTBH, LTBH | right and left most inferior rib |
| RTBL, LTBL | right and left lateral back on height of L4 |
| C3 , C5, C7 | third, fifth and seventh cervical vertebrae |
| T3, T5, T7, T9, T11 | third, fifth, seventh, ninth and eleventh thoracic vertebrae |
| L1, L2, L3, L4, L5 | first, second, third, fourth and fifth lumbar vertebrae |
| RTAS, LTAS | right and left anterior superior iliac spine |
| RTPS, LTPS | right and left posterior superior iliac spine |
| RTMS, LTMS | right and left mid superior iliac spine |
| SACR | sacrum |

**Table 2: Segmental allocation.**

| | |
|---|---|
| Lumbar spine | L1, L2, L3, L4, L5 |
| Thoracic spine | T3, T5, T7, T9, T11 |
| Pelvic segment | RTAS, LTAS, RTPS, LTPS, RTMS, LTMS, SACR |
| Lumbar segment | L1, L2, L3, L4, L5, LTBL, RTBL |
| Thoracic segment | T3, T5, T7, T9, T11, LTSC, RTSC, LTBH, RTBH, STER |
| Upper trunk segment | C7, LTSH, RTSH, RTCL, LTCL |

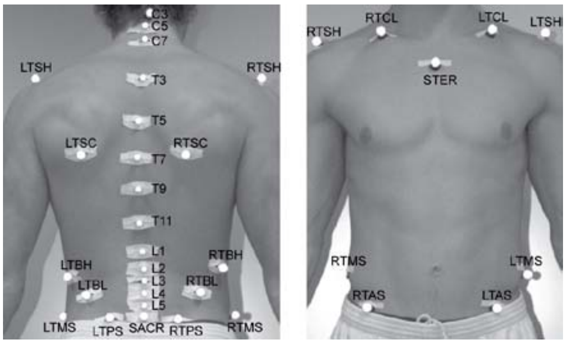


**Figure 1. Marker set of the trunk and the pelvis. For explanation of abbreviations see Table 1, for segmental allocation see Table 2.**

**RESULTS:** For all weight conditions and squat types segmental rotation was predominant in the sagittal plane, rotation in the frontal and the transverse plane were small (mean over four subjects: ROM lateral bending < 2.8°, ROM axial rotation < 3.6°). Pelvic relative to lumbar segmental sagittal rotation showed larger ROM for **r** (mean over four subjects: 0% BW: 22.7 ± 3.2°, 25% BW: 20.9 ± 2.7°, 50% BW: 18.3 ± 2.5°) compared to **unr** (mean over four subjects: 0% BW: 19.1 ± 2.6°, 25% BW: 17.9 ± 4.6°, 50% BW: 17.3 ± 1.8°) (see Figure 2). The lumbar spine curvature decreases with additional load, whereas the thoracic curvature is not dependent on loading (see Figure 3).

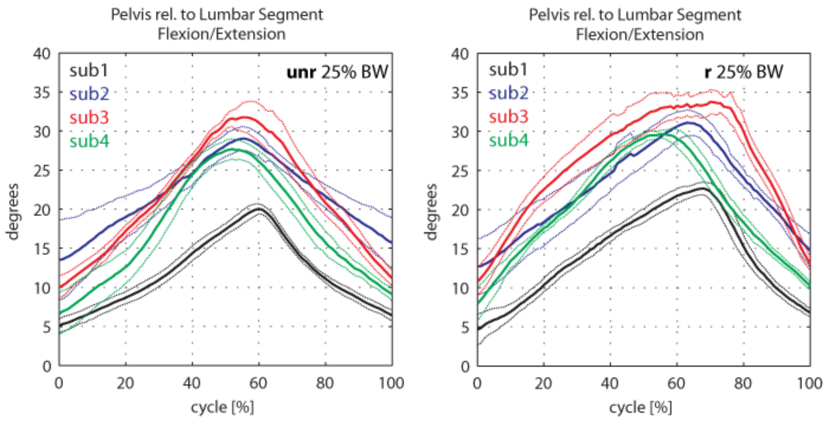


**Figure 2. Pelvic relative to lumbar segmental sagittal rotation. Mean and SD over 8 cycles. unr 25% BW (left), r 25% BW (right).**

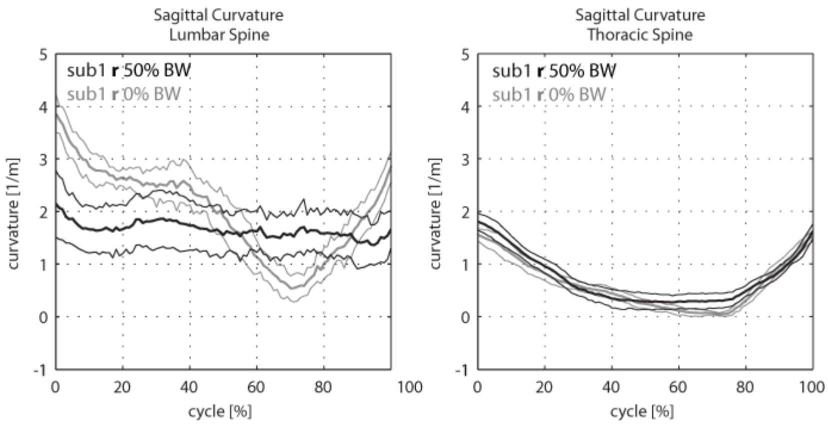


**Figure 3. Sagittal curvature of the lumbar (left) and thoracic (right) spine of sub1. Mean and SD over 8 cycles. r 0% BW (grey), r 50% BW (black).**

**DISCUSSION:** A marker set and its corresponding data processing has been developed that allows the assessment of the kinematics of the trunk in terms of a 3D segmental approach based on three trunk and one pelvic segment as well as in terms of a sagittal plane spine curvature analysis. Both approaches are suitable to assess the movement of the trunk during squatting.
A restriction in knee motion results in an increased trunk flexion. Assuming a simple mechanical model, this leads to higher stresses in the lower back. The load dependent straightening of the spine is in agreement with the study of Meakin et al. (2008).

**CONCLUSION:** In this study the 3D segmental motion of the trunk, based on a three segment trunk model, as well as the spinal sagittal curvature was determined. Given by the skin marker approach, the present method is limited by skin movement artefacts.
Not surprisingly, the ROM of flexion between the pelvic and the lumbar segment during squatting increases with a restriction in knee motion. Therefore, the stress on the lower back most likely is lower during an unrestricted squat. For these reasons, the unrestricted squat may be the right choice for most athletes.

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