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Morpho-functional interbone parameters in supine versus standing position – Comparison of CT and EOS Alignment

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Abstract

Morpho-functional interbone parameters of the knee are often used in clinical practice to assess the functional anatomy of the individual patient. Respective parameters, such as the TT-TG distance, are regularly measured manually on CT or MRI images. To overcome this time-consuming process, an automated framework for knee morphological analysis was previously presented by our group. A relevant remaining limitation, however, is the imaging performed in supine and not in an active, weight-bearing position, which was addressed in this study.

Data from 7 patients (14 knees) scheduled for total hip arthroplasty were used for this study. After segmentation, the CT-derived bone surface models were matched to the EOS images based on landmarks, with manual control and optional correction. Subsequently, the automated framework for morphological analysis was applied.

A statistically significant difference in mean was found for the joint rotation. The other mean deviations were not statistically significant and below the parameters' standard deviation, whereas the absolute deviations were higher. This fact highlights the relevance of inter-individual differences in supine versus standing interbone parameter measurements.

In general, large discrepancies regarding the changes in interbone parameter measurements from supine to standing position were found in the literature. The results of this study are plausible with regard to theoretical biomechanical relations. Overall, the study motivates an interbone parameter assessment in a standardized, active weight-bearing position. With further automation in data pre-processing, the workflow could be applied to large databases and hence be used to define reference ranges of interbone parameters in various poses.

1 Introduction

Morpho-functional interbone parameters are of particular interest in orthopedics, including diagnosis of pathology, treatment planning and post-operative control. Well-known interbone parameters of the lower extremity are the tibial tuberosity to trochlear groove (TT-TG) distance, femorotibial joint rotation, or indices measuring the patellar height, which for example serve as predictors of recurrent patellar dislocation (Chen et al. 2023). For several parameters, cut-off values have been defined in the literature to provide therapy recommendations. A well-known example is the cut-off value of 20 mm for the TT-TG distance, for which (when exceeded) a TT medialization is recommended (Dejour et al. 1994).

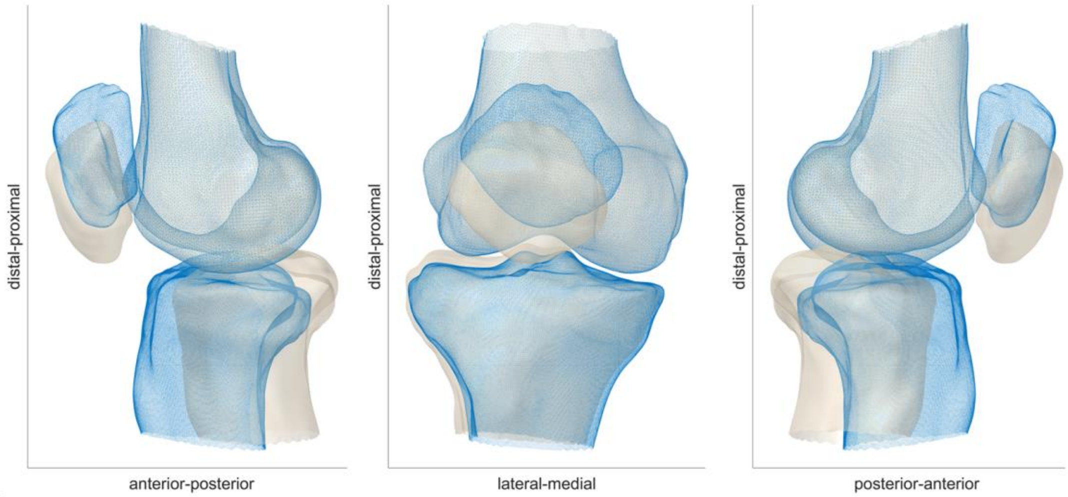
The basis for measuring respective morpho-functional interbone parameters regularly is three-dimensional bone surface data from computed tomography (CT) or magnet resonance imaging (MRI). Measurements are commonly performed manually, which is very time-consuming. A framework presented by our group enables the automated assessment of knee (interbone) parameters (Grothues et al. 2022; Asseln et al. 2018; Asseln and Radermacher 2019), addressing the limitation of a previously cumbersome manual process. However, another limitation remains, being the analysis of the patient in supine position, which is due to the setup of regular CT and MRI scanners. Specific Upright MRI and CT systems are available, however, they are infrequently used and not part of daily clinical practice (Hirschmann et al. 2015). Hence, morpho-functional interbone parameters are regularly measured in a passive, non-weight-bearing position without muscle activation and consequently minimal joint load. For the patient, however, the active, weight-bearing posture during activities of daily living is of interest. Studies on the influence of different poses and related effects (weight-bearing, muscle activation) on such detailed 3D interbone parameters of the knee (e.g., TT-TG) are limited.

Hence, the aim of this study was to analyze the change in morpho-functional interbone parameters from a supine to an active weight-bearing standing position, in a semi-automated framework.

2 Materials & Methods

The data analyzed originated from 7 patients (14 knees) scheduled for total hip arthroplasty. Both CT and EOS data were available, with the EOS imaging taken in a two-legged standing position, with one foot in front of the other. After segmentation of the CT images, the surface models derived were matched with the EOS images via landmarks. The final relative position was analyzed by one of the authors and corrected manually as needed. An exemplary comparison of the relative position of the bones in the CT versus in the EOS system is depicted in **Figure 1**. Subsequently, a previously presented workflow for morphological analysis of the knee was applied (Grothues et al. 2022; Asseln et al. 2018; Asseln and Radermacher 2019).

Statistical analyses were performed to assess the influence of the active weight-bearing position on parameter variance (Levene test) and mean (T-test or Welch test). Furthermore, a power analysis was performed to estimate the required number of cases (power: 80%, statistical significance: 5%).



(A) **(B)** **(C)**

Figure 1: Relative position of femur, tibia, and patella in the CT versus in the EOS system (blue) in different views: (A) medial-lateral view. (B) anterior-posterior view. (C) lateral-medial view.

3 Results

All knees were successfully analyzed with the semi-automated workflow. Three knees of fourteen knees analyzed were excluded from statistical analysis due to a failed plausibility test. Mean deviations between the parameters in supine versus standing position were below the parameters standard deviation, with the exception of the joint rotation. In contrast, absolute mean deviations were higher (~1 SD). This fact highlights the interindividual differences in parameter measurements performed in supine versus standing position.

The power analysis resulted in high numbers of sample sizes required for a power of 80%. The power with the given number of knees is provided in **Table 1**. Only for the joint rotation, a statistically significant difference in means was found. While the statistical significance of the other parameter deviations could not be demonstrated, their mean and absolute mean deviations can be evaluated from a clinical point of view. For example, the TT-TG distance for one candidate was not pathological in the supine position, whereas it exceeded the cut-off value of 20 mm in standing position. The quantitative results are summarized in **Table 1**.

Parameter	Mean NWB	Mean WB	Mean Deviation	Mean Abs. Deviation	Current Power (N=11)	Power 80%, N required	T-Test (h)
Patella Tilt	6.0° ± 8.3°	10.1°	4.0°	7.5	27 %	32	0
Patella Shift	2.4 mm ± 3.5 mm	4.2 mm	1.8 mm	3.3 mm	34 %	20	0
Congruence Angle	16.2° ± 38.9°	31.7°	15.5°	27.1°	22 %	52	0
TT-TG distance	9.3 mm ± 6.2 mm	8.2 mm	-1.1 mm	3.8 mm	9 %	1039	0
relative TT-TG distance	0.1 ± 0.08	0.1	-0.01	0.05	9 %	1218	0
Joint rotation	5.2° ± 4.7°	-1.5°	-6.8°	7.9°	99 %	**8**	**1**
Hip-knee angle	177.9° ± 4.2°	178.6°	0.6°	1.7°	7 %	821	0
Insall Salvati Index 3D	1.4 ± 0.11	1.3	-0.02	0.09	9 %	108	0

Table 1: Results of the morphological analysis and subsequent statistical analyses.

4 Discussion

Previous studies on interbone parameters of the knee such as the TT-TG distance have been primarily based on manual measurements from CT or MRI imaging, taken in supine position. In the present study, we have measured 8 interbone parameters in the active weight-bearing position by matching CT derived surface models to EOS images in standing position in a semi-automated workflow.

The **patella tilt** angle can be measured with respect to the anterior condylar line (PTA-A) (Sasaki and Yagi 1986; Laurin et al. 1978) or with respect to the posterior condylar line (PTA-P) (Kalichman et al. 2007). In our study, the patella tilt, measured as PTA-A, was generally found to increase from supine to standing position, with three exceptions. The results are in agreement with those of Leiprecht et al. (Leiprecht et al. 2021), who found an increase in PTA-A with weight-bearing. In contrast, Hirschmann et al. (Hirschmann et al. 2015) found a statistically significant decrease in PTA-A with weight-bearing. A possible explanation for the discrepancies identified may be that the patella tilt very much depends on the patient-specific morphology of the trochlea as the patella is engaged more into the trochlear groove with muscle contraction in the weight-bearing state. However, information on quadriceps activation was not available in our study or in the literature.

In the present study, a lateralization of the patella was found from supine to standing position for most of the knees. Powers et al. (Powers et al. 2003) found a decrease in lateral **patella shift** from ~30-9° of knee flexion, and an increase in the last degrees of extension (~6-0° knee flexion). In contrast, Hansen et al. (Hansen et al. 2023) found an increase in the bisect offset (which also quantifies lateral patellar shift) from supine to standing position. A lateralization of the patella could potentially be explained by activation of the quadriceps for stabilization of the standing position, which exercises a lateralizing force on the patella.

We generally found an increase in **congruence angle** with weight-bearing in our study, with four exceptions. In contrast, Kim et al. (Kim et al. 2014) found that the congruence angle decreases with weight-bearing in healthy knees. Generally, a positive congruence angle is noted if the patella ridge is positioned more laterally relative to the intercondylar sulcus. Hence, when the patella shifts laterally with engagement of the quadriceps muscle upon weight-bearing as hypothesized above, it can be assumed that the congruence angle increases.

In our study, we found a trend towards internal **tibial rotation** with weight-bearing. Similarly, Hirschmann et al. (Hirschmann et al. 2015) reported a change from external to internal tibial rotation with the adjustment from supine to upright position. The internal tibial rotation may be explained by quadriceps contraction in extension under joint load, as the lateralizing portion of the quadriceps muscle force pulls the femur outward. This fact highlights the limitation of passive ligament balancing in TKA, which targets the knee balance in a functionally rather irrelevant position which differs significantly from the active weight-bearing position.

We found a decrease in **TT-TG distance** from supine to standing position. The results are in agreement with those of Hirschmann et al. (Hirschmann et al. 2015) and Izadpanah et al. (Izadpanah et al. 2014). In contrast, Hansen et al. (Hansen et al. 2023) reported an increase in TT-TG distance from supine to standing position. A reduction of the TT-TG from supine to standing position could be explained by the observed internal tibial rotation upon weight-bearing, which would move the TT closer to the TG, which in turn would reduce the overall TT-TG distances.

Deep et al. (Deep et al. 2015) reported a previous varus up to 2.5° valgus alignment to increase in varus upon standing in healthy volunteers. Paternostre et al. (Paternostre et al. 2014) observed a varus shift in 44 % of knees already in varus, and a further valgus shift in 50 % of valgus knees, in patients scheduled for TKA. Consequently, the literature suggests no clear tendency for the **varus-valgus angle**, which is reflected in the results of this study.

In the literature, the patellar height in terms of the **Insall Salvati Index** was found to either decrease slightly with weight-bearing (Hansen et al. 2023) or to increase slightly (Leiprecht et al. 2021; Yiannakopoulos et al. 2008; Narkbunnam and Chareancholvanich 2015). Similarly in our study, both knees with an increase and a decrease in Insall Salvati Index were found with an overall mean deviation of -0.02 ± 0.12.

This study involved limitations. The EOS standing position (one foot in front of the other) may slightly differ from regular two-legged standing position analyzed in the literature. In addition, parameter differences between the leg in front and the one in the back may be present, which need to be evaluated in the future.

5 Conclusion

With the exception of the joint rotation, mean deviations found in this study were not statistically significant and below the parameters' standard deviation. The absolute mean deviations were almost twice the mean deviations, which emphasizes the importance of inter-individual differences in respective parameter changes. In general, large discrepancies regarding the changes from supine to standing interbone parameters were found in the literature. Possible explanations include differences in the standing pose and in the level of muscle activation. Overall, this study motivates the assessment of interbone parameters in a standardized, active standing position through modern imaging techniques such as Upright CT and MRI or DVT imaging or by CT to EOS matching as presented here.

As an outlook, the automation and robustness of the CT to EOS matching (data pre-processing) should be increased to allow for the analysis of larger databases and subsequent definition of reference ranges in various functional poses. Further, the suitability of conventional diagnostic long-leg radiographs for a respective matching process should be evaluated.

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