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HIP

Frontal knee alignment influences the vertical orientation of the femoral neck in standing position

S. S. Ahmad,
L. Weinrich,
G. M. Giebel,
M. R. Beyer,
U. Stöckle,
C. Konrads

From Charité Berlin, Berlin, Germany

Aims

The aim of this study was to determine the association between knee alignment and the vertical orientation of the femoral neck in relation to the floor. This could be clinically important because changes of femoral neck orientation might alter chondral joint contact zones and joint reaction forces, potentially inducing problems like pain in pre-existing chondral degeneration. Further, the femoral neck orientation influences the ischiofemoral space and a small ischiofemoral distance can lead to impingement. We hypothesized that a valgus knee alignment is associated with a more vertical orientation of the femoral neck in standing position, compared to a varus knee. We further hypothesized that realignment surgery around the knee alters the vertical orientation of the femoral neck.

Methods

Long-leg standing radiographs of patients undergoing realignment surgery around the knee were used. The hip-knee-ankle angle (HKA) and the vertical orientation of the femoral neck in relation to the floor were measured, prior to surgery and after osteotomy-site-union. Linear regression was performed to determine the influence of knee alignment on the vertical orientation of the femoral neck.

Results

The cohort included 147 patients who underwent knee realignment-surgery. The mean age was 51.5 years (SD 11). Overall, 106 patients underwent a valgisation-osteotomy, while 41 underwent varisation osteotomy. There was a significant association between the orientation of the knee and the coronal neck-orientation. In the varus group, the median orientation of the femoral neck was 46.5° (interquartile range (IQR) 49.7° to 50.0°), while in the valgus group, the orientation was 52.0° (IQR 46.5° to 56.7°; $p < 0.001$). Linear regression analysis revealed that HKA demonstrated a direct influence on the coronal neck-orientation ($\beta = 0.5$ (95% confidence interval (CI) 0.2 to 0.7); $p = 0.002$). Linear regression also showed that realignment surgery was associated with a significant influence on the change in the coronal femoral neck orientation ($\beta = 5.6$ (95% CI 1.5 to 9.8); $p = 0.008$).

Conclusion

Varus or valgus knee alignment is associated with either a more horizontal or a more vertical femoral neck orientation in standing position, respectively. Subsequently, osteotomies around the knee alter the vertical orientation of the femoral neck. These aspects are of importance when planning osteotomies around the knee in order to appreciate the effects on the adjacent hip joint. The concept may be of even more relevance in dysplastic hips.

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Correspondence should be sent to Sufian S Ahmad; email: sufian@ahmadortho.com

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Introduction

Alignment of the lower limb has been in the spotlight in the orthopaedic world in recent decades, due to the pronounced effects of bony pathomorphology on the occurrence of musculoskeletal disorders;[1-6] for example, varus or valgus deviations around the knee leading to early gonarthritis.[1-3] Research activity in the field is constantly thriving alongside the development of osteotomy

concepts for alignment correction.[3,7] It is to be underlined that the understanding of the effects of an osteotomy on the complex biomechanics of the skeletal system is not yet sufficient.[8]

In particular, surgeons frequently underappreciate the effect of an osteotomy on adjacent joints.[8] This is partly due to either an insufficient workup or the lack of available knowledge of the literature. This is also a result of subspecialization that may sometimes limit a broader evaluation of a pathological condition of a joint.[9] The necessity of quality research in the field can therefore only be underlined in order to allow for the establishment of algorithmic decision trees that appreciate the entire skeletal morphology of the limb beyond the boundaries of a single joint.

The coronal femoral neck orientation is frequently in valgus and is based on the centrum column diaphyseal (CCD) angle.[10] However, the alignment of the knee may alter the orientation of the diaphysis of the femur and consequently the horizontal alignment of the femoral neck with respect to the floor.[11] Joint reaction forces are higher in valgus hips, potentially leading to early coxarthritis.[11]

It was therefore the aim of this study to determine the association between the alignment of the knee and the coronal femoral neck orientation in space. It was hypothesized that a valgus knee alignment morphology was associated with a valgus orientation of the femoral neck to the floor in standing position. It was further hypothesized that realignment surgery around the knee is likely to alter the orientation of the femoral neck.

Methods

Patients aged between 18 and 69 presenting with a knee malalignment disorder between January 2017 and December 2018 were considered eligible for inclusion in the study, provided that the following criteria were met: frontal realignment surgery was performed; pre- and postoperative radiographs that included the hip, knee, and ankle joints in an upright standing position centred around neutral knee positions; postoperative radiographs were taken after union at the osteotomy site. Patient consent was necessary for inclusion in the analysis. Patients aged below 18 years or above 69 years were excluded, as were those with missing or inadequate postoperative image quality (e. g. hips or ankles not fully pictured).

Surgical procedure. All osteotomies were planned using a landmark based deformity analysis. High tibial osteotomy was performed as described by Staubli et al[12] and Lobenhoffer et al[13] using a TomoFix MHT plate fixator (DePuy Synthes, Switzerland).[14] Distal femoral osteotomy was performed as described by Lobenhoffer.[15]

Radiographs. Long-leg weightbearing radiographs were obtained according to the description from Paley and Herzenberg,[16] using a 1.3 m cassette (Global Imaging, USA). The patient had to stand in a bipedal stance in front of a long film cassette. The X-ray tube was positioned at a distance of 3.05 m. The magnification with this setup was 5%. A 2.5 cm steel ball was used for calibration. The X-ray beam was centred at the level of the knee joints. It was ensured that the patellae were positioned in such a way that they were between both condyles pointing forward. The radiographs were all performed in a standardized manner and were obtained preoperatively and after union of the osteotomy.

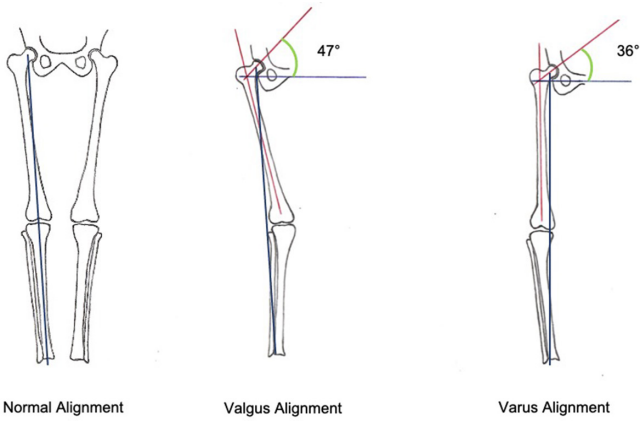

Fig. 1

An illustration demonstrating the concept of the influence of frontal knee alignment on the vertical orientation of the femoral neck. The valgus knee demonstrates a more vertical orientation of the femoral neck (middle), while a varus knee demonstrates a more horizontal orientation (right image).

Several radiological measures were used for the purpose of the study. Alongside the known hip-knee-ankle angle (HKA)[16] of the lower limb that was obtained prior to surgery and after surgery, the coronal orientation of the femoral neck in relation to the floor was measured. This angle was defined for the purpose of this study, therefore representing the primary outcome measure. The coronal orientation of the femoral neck in relation to the floor was measured by drawing the axis of the femoral neck and a horizontal line. An example is given in Figure 1 where the angle is 47° in the depicted case with valgus knee alignment and 36° in the varus case.

As secondary outcome measures, the lateral centre-edge angle (LCE) of the hip as well as the centrum-collum-diaphyseal angle (CCD) were measured.[17] The extrusion index was also measured and defined as the percentage of uncovered femoral head in comparison to the total horizontal head diameter.[18]

Ethical approval was received for the conduction of this study by our university's review board under the project number 421/2020BO.

Statistical analysis. Values were presented as median and interquartile range (IQR). Non-parametric data were compared using the Mann-Whitney U test. Linear regression

Table I. Characteristics of the varus group undergoing valgization osteotomy.

Radiological measures	Preoperative	Postoperative	p-value*
Median HKA, ° (IQR)	-6.5 (8.5 to -4.5)	2.0 (0.9 to 3.5)	< 0.001
Median femoral neck angle, ° (IQR)	46.5 (49.7 to 50.0)	48.3 (44.0 to 51.9)	0.068
Median CCD, ° (IQR)	130 (126 to 134)	129.8 (126 to 134)	0.661
Median LCE, ° (IQR)	31.8 (27.2 to 36.4)	31.5 (27.6 to 36.8)	0.610

*Mann-Whitney U test.
CCD, centrum-collum-diaphyseal; HKA, hip-knee-ankle; IQR, interquartile range; LCE, lateral centre-edge.

Table II. Characteristics of the valgus group undergoing varization osteotomy.

Radiological measures	Preoperative	Postoperative	p-value*
Median HKA, ° (IQR)	5.7 (4.1 to 8.6)	-1.7 (-2.8 to 0.6)	< 0.001
Median femoral neck angle, ° (IQR)	52.0 (46.5 to 56.7)	49.5 (45.3 to 54.7)	0.059
Median CCD, ° (IQR)	132.6 (129.2 to 137.2)	133.4 (128.6 to 141.3)	0.602
Median LCE, ° (IQR)	32.2 (28.5 to 36.5)	31.4 (27.3 to 37.9)	0.528

*Mann-Whitney U test.
CCD, centrum-collum-diaphyseal; HKA, hip-knee-ankle; IQR, interquartile range; LCE, lateral centre-edge.

was performed to test the influence of input variables in the coronal orientation of the femoral neck. A p-value of < 0.05 was considered statistically significant. Statistical tests were performed using SPSS statistics v. 27 (IBM, USA). Intraclass correlation coefficient (ICC) estimates and their 95% confidence intervals (CIs) were calculated using the same software.

Results

The cohort included 147 patients that had undergone knee realignment surgery in a single institution. The mean age was 51.5 years (standard deviation 11 years). Of the included patients, 106 underwent a valgisation osteotomy, while 41 underwent varisation osteotomy. The preoperative and postoperative radiological values of the corresponding two groups are illustrated in Tables I and II

In the native (preoperative) legs, there was a significant association between the orientation of the knee and the coronal neck orientation. In the varus group, the orientation of the femoral neck was 46.5° (IQR 49.7 to 50.0), while in the valgus group, the orientation was 52.0° (IQR 46.5 to 56.7; p < 0.001, Mann-Whitney U test) (Figure 2).

After alignment correction osteotomy, which was performed to correct the valgus alignment in the valgus group and the varus alignment in the varus group, the final orientation of the femoral neck did not differ between both groups (p = 0.401, Mann-Whitney U test).

The LCE angle did not differ between the both groups of varus or valgus knee alignment (p = 0.664, Mann-Whitney U test). The extrusion angle also showed no difference between valgus and varus aligned knees (p = 0.662, Mann-Whitney U test).

Linear regression analysis revealed that HKA demonstrated a direct influence on the coronal neck orientation (β = 0.5 (95% CI 0.2 to 0.7); p = 0.002) (Figure 2). Linear regression also showed that realignment surgery was associated with a significant influence on the change in the coronal femoral neck orientation (β = 5.6 (95% CI 1.5 to 9.8); p = 0.008).

For intra- and interobserver reliability and repeatability analysis regarding the method of measuring the coronal orientation of the femoral neck to the floor (horizontal line) on long leg standing radiographs (Figure 1), the ICC was determined as 0.89 and 0.93, respectively, demonstrating good to excellent levels of reliability.

Discussion

The findings of this study underline the association between the frontal knee alignment and the vertical orientation of the femoral neck.

The most important parameter that is commonly used for determination of femoral neck morphology has always been the centrum column diaphyseal (CCD) angle. This angle represents the association between the femoral neck and the diaphysis of the femur. However, this is a pure depiction of the bony morphology of the proximal femur. In an upright standing position, the orientation of the femoral diaphysis would influence the vertical orientation of the femoral neck in relation to the pelvis. The knee alignment has been shown to determine that orientation by abduction or adduction of the femur in standing position. This can easily be explained: the patient abducts or adducts in the hip, positioning the leg for full contact between the foot and the floor. In a varus knee the patient tends to abduct the hip, whereas in a valgus knee, the patient tends to adduct the hip.

The clinical relevance of the findings of this study is underlined by the importance of understanding the influence of realignment surgery around the knee on adjacent joints.[1,8] This is also relevant in the field of joint arthroplasty that involves alteration of the alignment of the knee.[19,20]

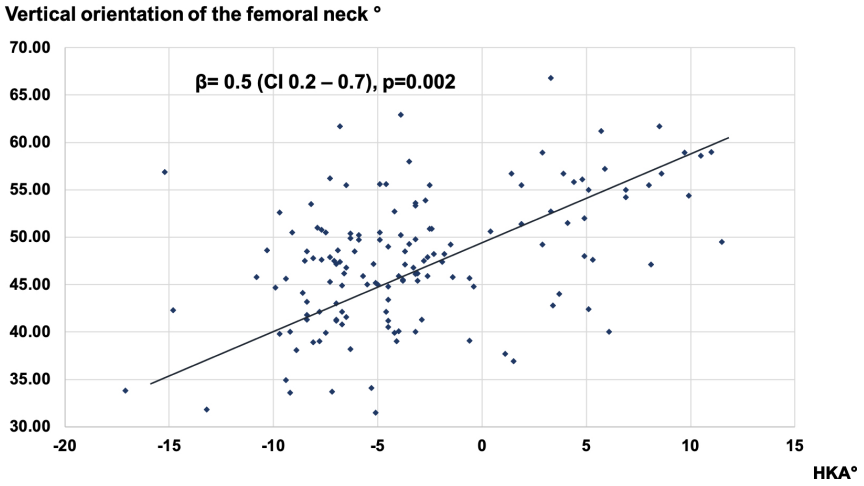

Fig. 2

Linear regression demonstrating the association between the frontal knee alignment (hip-knee-ankle angle (HKA)) and the vertical orientation of the femoral neck. CI, confidence interval.

The frontal orientation of the femoral neck and its association with knee alignment has never actually been linked. Although the results of this study clearly managed to demonstrate the link between frontal knee alignment and the frontal orientation of the femoral neck, therapeutic implications are yet to be defined. The cohort of patients examined in this study showed normal acetabular coverage with a mean LCE angle of 31°. Therefore, the change of the frontal orientation of the femoral neck did not influence coverage of the femoral head. This may differ in patients with hip dysplasia, presenting with reduced acetabular coverage. A change in the frontal orientation of the neck may influence the functional coverage of the dysplastic hip. This phenomenon has been shown in correction of leg length discrepancy which, similar to osteotomies around the knee, result in abduction or adduction of the femoral shaft.[21,22] As a matter of fact, there have been case reports of limb-lengthening as a treatment for patients with functional dysplasia of the hip joint, resulting from an adducted contralateral long limb.[23] In a published study including patients with hip osteoarthritis and leg length discrepancy, the side baring the longer leg demonstrated a significantly increased likelihood of being diseased.[24] The concept therefore deserves emphasis in patients undergoing correction osteotomies around the knee.

The limitations of this study can be underlined by the fact that clinical outcome measures were not included. This was due to the primary research question that was based on a radiological proof of concept. The results should be sufficient for that purpose. Furthermore, it would be interesting to look into particular morphological cohorts including dysplastic hips and furthermore include rotational aspects. These questions are undoubtedly of interest and require further intensive research. A bigger sample size might lead to higher levels of significance. In the investigated cohort, the average correction of coronal alignment was not huge, given that the cohort did not consist of patients with extreme deformities and the target of the corrective osteotomy was a physiological alignment.

In conclusion, varus or valgus knee alignment is associated with either a more horizontal or a more vertical femoral neck orientation in standing position, respectively. Subsequently, osteotomies around the knee alter the vertical orientation of the femoral neck. These aspects are of importance when planning osteotomies around the knee in order to appreciate the effects on the adjacent hip joint. The concept may be of even more relevance in dysplastic hips.

Take home message

- This study clearly demonstrates an association between the frontal alignment of the knee and the vertical orientation of the femoral neck in relation to the pelvis.
- These aspects are of importance when planning osteotomies around the knee, given that valgization of the knee will increase the vertical orientation of the neck and varization will decrease it.
- The concept may be of even more relevance in dysplastic hips.

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Author information:
- S. S. Ahmad, MD, Consultant Orthopaedic Surgeon, Department of Trauma and Reconstructive Surgery, University of Tübingen, Tübingen, Germany; Center for Musculoskeletal Surgery, Charité Universitätsmedizin Berlin, Berlin, Germany.
- L. Weinrich, MD, Resident
- G. M. Giebel, MD, Resident
- U. Stöckle, MD, Professor
  Center for Musculoskeletal Surgery, Charité Universitätsmedizin Berlin, Berlin, Germany.
- M. R. Beyer, MD, Resident
- C. Konrads, MD, Senior Consultant Orthopaedic Surgeon
  Department of Trauma and Reconstructive Surgery, University of Tübingen, Tübingen, Germany.

Author contributions:
- S. S. Ahmad: Conceptualization, Methodology, Formal analysis, Writing – original draft.
- L. Weinrich: Investigation.
- G. M. Giebel: Formal analysis, Writing – review & editing.
- M. R. Beyer: Formal analysis, Visualization, Writing – review & editing.
- U. Stöckle: Supervision.
- C. Konrads: Conceptualization, Methodology, Project administration, Investigation, Formal analysis, Validation, Visualization, Writing – original draft, Writing – review & editing.

- S. S. Ahmad and L. Weinrich contributed equally to this work.

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