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# The effect of weight-bearing positions on coronal lower limb alignment: a systematic review

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*WC:* Designed the study, Performed the literature search, reviewed the articles, analyzed and interpreted the data, prepared the manuscript. LVB: reviewed the articles, analyzed and interpreted the data, prepared the manuscript *LB:* performed the statistical analysis, analyzed and interpreted the data *LS:* analyzed and interpreted the data, reviewed the manuscript *JB:* designed the study, analyzed and interpreted the data, reviewed the manuscript

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## Abstract

**Introduction:**

The coronal alignment of the lower limb is generally accepted as a major determinant of surgical outcome in total knee arthroplasty (TKA). To achieve the ideal post-operative alignment, surgeons need to be aware of the influence that weight-bearing positions have on the final knee alignment.

Therefore, this review aims to define the effect of varying weight-bearing positions on the coronal alignment of the lower limb. We hypothesized that a coronal alignment deformity increases with loading.

**Material and methods:**

The PubMed, Medline and google scholar databases were searched systematically in June 2022. Only studies which compared coronal alignment with a standardized radiographic protocol in the single leg, double leg and supine positions were included. To obtain pooled estimates of the effect of different weight-bearing positions, random-effect analysis were fitted using SAS.

**Results:**

Compared to the supine position, double leg weight-bearing positions were found to be associated with a more pronounced varus deformity (mean difference in HKA is 1,76° (95% CI 1,32: 2,21), $p < 0.0001$)). The mean difference in HKA between double leg and single leg weight-bearing conditions was 1.43° (95% CI (-0,042;2,90), $p = 0.0528$).

**Conclusion:**

The overall knee alignment was found to be influenced by the weight-bearing position. An average difference of 1.76° in HKA-angle was found between a double leg-stance and supine position, tending to increased varus in the former weight-bearing position. It is therefore possible that the deformity could increase by 1.76° if knee surgeons only follow a pre-op planning based on double-leg stance full length radiographs.


## Introduction

In total knee arthroplasty (TKA), coronal alignment of the lower limb as well as restoration of the mechanical axis are generally accepted as major determinants of surgical outcome[1,2]. As a consequence, reproducible and precise measurements of the coronal alignment of the lower limb are required in TKA, whether performed during the planning, execution or post-surgical assessment [3]. Weight-bearing conditions are thought to influence the assessment of the coronal alignment of the lower limb[4]. Moreover, the effects of the loss of cartilage and ligamentous imbalance can only be visualized best by using such weight-bearing assessments[5]. Mechanical factors such as gravity or muscle strength in the weight-bearing positions play an important role in the health and disease progression of the knee[6,7,8]. There are many biomechanical variables related to the knee function, but the most commonly explored is the external knee adduction moment (KAM). The knee adduction moment is a surrogate measure for the medial compartment loading of the knee joint during walking[9]. By passing medially to the knee joint center, the force vector creates an adduction moment that is thought to increase the medial compartment load[10].

The external knee adduction moment is mainly determined by the ground reaction force (GRF) and its lever arm to the knee joint center. The ground reaction force is according to Newton's third law; the equal and opposite force that was applied to the ground[11].

A double stance positioning can distribute the loads between two legs, whereby the reaction force will be less in comparison to a single leg stance position. So, a greater adduction moment has already been described to force the knee into varus during a single leg stance[12]. Knowing that the single-leg stance represents 60 percent of the loads during a gait cycle, the single-leg stance is most representative for the loads on the knee[11,13]. Until now, the double stance full leg antero-posterior radiograph of the lower limb is generally accepted as the clinical gold standard to assess the coronal alignment of the lower limb. Knee surgeons therefore need to be aware of the difference in knee alignment in double-stance and single-stance assessments. Moreover, positioning a patient in a supine position will eliminate the ground reaction force on the knee. Since the knee adduction moment was described as forcing the knee into varus during increasing weight-bearing[14], an underestimation of the alignment deformity can be expected in patients in the supine position. As all patients have a supine position during total knee arthroplasty, the effect of all different weight-bearing conditions on the final knee alignment needs to be known. Knee surgeons have to be aware of this to achieve the ideal post-operative alignment, since this is a major determinant of the surgical outcome. By making a comparison between radiological and computer navigation measurements, Willcox et al concluded that the intra-operative alignment obtained from computer navigation is not necessarily the same as the deformity seen on a standing long-leg radiograph[5].

This review aims to define the effect of weight-bearing conditions on the coronal alignment of the lower limb. The differences between supine, non-weight-bearing and weight-bearing conditions will be investigated, as well as the effect of amount of weight-bearing, expressed by single leg or double leg stance. As flexion or rotational deformities of the lower extremity and patient positioning during imaging can influence the accuracy of two-dimensional measurements[15], we will take into account the imaging technique that was used

We hypothesized that a coronal alignment deformity increases from a supine, non-weight bearing to a standing, weight-bearing position and will be most pronounced in single leg stance.

## Material and Methods

### *Search strategy*

A literature search was performed with PubMed, Medline and Google scholar by one author in June 2022.

The Mesh terms were based on a preceding PICO-analysis.

Search parameters used for the PubMed database were: Knee joint/ diagnostic imaging [Mesh] AND posture AND weight-bearing, Knee joint/ diagnostic imaging [Mesh] AND posture AND supine position , Knee joint/ diagnostic imaging [Mesh] AND posture AND limb loading , Radiographic Image interpretation AND limb loading , lower extremity/diagnostic imaging AND weight bearing AND supine , Lower limb alignment and weight bearing and supine position , full length X-ray and weight bearing and supine position.

The search parameters used for Medline were: Lower limb alignment and weight bearing and supine position, Full leg X-ray, lower limb full-length x-ray, Full-length radiographs, full leg standing radiographs, Lower limb coronal alignment, LLR AND knee, mesh(posture) AND mesh (weight bearing) AND mesh(radiography), mesh(radiography) AND mesh (weight bearing) AND mesh(knee).

The search parameters used for Google scholar were: “supine long leg x-ray” and “Differences in coronal knee-alignment between standing and supine x-ray”.

### *Eligibility criteria*

Applied measurement-methods needed to be validated to allow inclusion of studies. Studies without a standardized radiographic protocol were excluded. Other exclusion criteria were: (1) studies which compared lower limb alignment based on ‘gait-analysis’, (2) no information of the weight-bearing status of the participants is provided, (3) the study lacks coronal measurements. In addition, only studies with comparisons between different weight-bearing situations (single leg, double leg and supine), were included. Only studies with a reported standard deviation and standard error could be included to allow for further statistical analysis.

Selection process

Records obtained from the literature research were title screened by one author. The retrieved articles were assessed for eligibility by two authors independently. Additionally, all included articles were reviewed by 2 authors in terms of quality using the 5-point Oxford Quality rating Scale and CONSORT checklist [16].

*Data processing and statistical analysis*

According to the Prisma guidelines, tables were made to classify and integrate the retrieved data[17,18]. To rule out any bias of possible inaccurate measurements of two-dimensional assesments[33,34,35,36], a distinction was made between studies which used the same digital imaging techniques and those who made comparisons of different ones. A first table investigated studies which used the identical imaging systems. A second table was defined for data from studies who made comparisons of non-identical imaging systems. Furthermore, 3 subgroups were defined based on the pre-existing knee alignment. A first subgroup consisted of studies which only included varus knees. The second subgroup consisted of studies which included a combination of both varus and valgus knees. Studies which only included valgus knees constituted the third and final subgroup. For each subgroup the effect of weight bearing conditions on coronal alignment was determined.

To obtain pooled estimates of the effect of different weight-bearing conditions for identical medical imaging systems, random-effects meta-analyses were fitted using the PROC MIXED function in SAS, version 9.4[19]. Separate models were defined for the comparison of double leg versus supine weight-bearing positions, for double leg versus single leg positions, and for single leg versus supine weight-bearing conditions, with the difference in HKA between each pair of measurement positions as the dependent variable. The variances of these differences were used as within study variances and the between study variance was estimated via the restricted maximum likelihood (REML) method, by including a random study effect in the model. To obtain the effect of the double leg versus supine weight-bearing position for non-identical medical imaging systems, the models were extended with a categorical fixed effect specifying the medical imaging systems used (i.e., FLR vs CT, FLR vs computer-assisted surgery (CAS), FLR vs MRI and biplanar radiography 3D vs CT).

## Results

In total, 758 articles were identified in this literature search. After screening the titles, removal of duplicates and adding articles after manual screening of the reference lists, 59 studies were reviewed by 2 authors. Of these, 33 were excluded based on the above criteria leading to 26 studies. After using the statistical inclusion criteria, a total number of 15 articles were finally analyzed (fig 1.).

Fig. 1: This illustrates the PRISMA flowchart of paper selection.

Six different assessment methods for lower limb alignment were reported in the remaining 15 studies: 2D full length X-ray, 3D full length X-ray (EOS), CT scan, MRI, CAS, and a validated non-invasive infrared position capture system. Three different weight-bearing conditions were reported: (1) single leg stance, (2) double leg stance and (3) the supine position.

1. A comparison of double leg weight-bearing vs supine conditions

A distinction was made between studies which used the same digital imaging techniques and those who compared different ones.

Three studies[12,21,22] were included, based on the use of identical imaging modalities.
Based on these studies, double leg weight bearing positions were found to be associated with a more pronounced varus alignment compared to the supine position. The mean difference in HKA between double leg and supine position was 1,68° (95% CI 0,51: 2,85), p = 0,0197). Detailed results are shown in table 1.

Table 1.: An overview of the studies who used identical radiographic imaging modalities to determine the influence on knee alignment between the supine position and a double leg stance position. The knee alignment tends to a more varus alignment than in a double leg stance position.

Eight studies[5, 23,24,25,26,27,28,29] were found that compare double leg stance with a supine position, based on non-identical imaging modalities. In total, five different imaging systems were used throughout these studies. The full-length radiograph and 3D biplanar radiography were compared to CT/CT scanogram, MRI, CAS and an intraoperative supine fluoroscopy respectively.

These studies showed an overall mean difference in HKA of 1.80° (95% CI (1,21;2,39) (p = 0,0001), tending to increased varus in the double leg weight-bearing position.

a. full length radiograph vs CAS

Three studies[5,23,24] were found to describe this difference (see table 2). The mean difference in these studies was 1,87° (95% CI [0.42;3.34]p=0.0233) tending to a more varus alignment in standing full length radiograph.

Table 2.: The effect of weight-bearing measurements analyzing 2D full length radiograph vs computer navigation: double leg stance vs supine position. The final knee alignment tends to a more varus alignment in the double stance position.

b. full length radiograph vs MRI

The mean difference between standing full length radiographs and supine MRI was 2,21° (95%CI [ 0.36; 4.07] p = 0.0294). This was based on studies by Winter et al.[25] and Schoenmakers et al.[24] (see table 3).

Table 3.: The difference in HKA-angle between full length radiographs (double leg stance) vs MRI (supine). The overall knee alignment measurements tend to a more varus alignment in full length double stance radiographs when compared to supine MRI's.

c. full length radiograph vs CT

Two studies[26,27] described the difference between standing full length radiographs and supine CT's (table 4). The HKA-angle changed by 1,61° (95%CI [--0,25;3.48], p=0,0745) towards a more varus position in the standing full-length X-rays.

Table 4: The difference in HKA-angle between full length radiographs (double leg stance) vs CT (supine). The overall knee alignment measurements tend to a more varus alignment in full length double stance radiographs compared to supine CT's.

d. biplanar 3D radiography vs CAS

Only one study compared the intra-operative CAS measurements (supine) to standing EOS 3D reconstructions. When comparing varus/valgus angle measurements of CAS with preoperative EOS 3D measurements, greater varus and valgus angles were measured with EOS 3D for varus and valgus knees respectively by Meijer et al.[28] . Preoperatively, a varus-valgus angle of 0° for CAS and -3° for EOS 3D were measured with a statistically significant difference of 3°.

e. biplanar 3D radiography vs CT (supine) vs full length radiograph

One study was found. The results of the study by Guggenberger et al.[29] regarding the coronal alignment showed a mean HKA of 2,3°± 5,5° for supine CT, 2,5°± 6,7° for FLR and 3,4°± 6,6° for biplanar linear radiographs. Measurements on biplanar linear radiographs were 1,1 ± 2,5° more varus compared to a supine CT. The difference between biplanar 3D radiography and full-length radiography was 0,9° ± 3,1°, tending to more varus in the upright FLR.

The overall mean difference of HKA between double leg and supine position was determined using the eleven studies above[5,12,21,22,23,24,25,26,27,28,29], the imaging modality used was not taken into account. The overall delta HKA is 1,76°,95%CI (1.32;2.21), $p<0.0001$ tending to more varus in a double leg stance. All delta HKA's are summarized in table 5.

Table 5: An overview of all included studies. A distinction was made between the three different weight-bearing positions and the pre-operative knee alignment. Studies which only included varus knees were marked in green. Studies which included a combination of both varus and valgus knees were marked in red. Delta HKA shows a clear tendency towards varus related to the more weight-bearing positions.

2. A comparison of double leg vs single leg weight-bearing conditions

Three studies[12,30,31], which all used identical imaging modalities, were included to investigate the differences between single leg and double leg weight bearing conditions.

These results are summarized in table 6. The mean difference in HKA between double leg and single leg weight bearing conditions was 1.43° (95% CI (-0,042;2,90), p = 0.0528). The latter showing a more varus alignment.

Table 6.: An overview of the studies who used identical radiographic imaging modalities to determine the different influence on knee alignment between the double leg stance and the single leg stance position. The knee alignment tends to more varus in a single leg stance position.

3. A comparison of single leg weight-bearing vs supine conditions

Two studies[12,32] were found to analyze this difference (table 7). Those studies used identical imaging modalities.

The mean difference in these studies was 2.08 [0.86; 3.31] (p = 0.0295) tending to a more varus alignment in single leg stance.

Table 7.: An overview of the studies which used identical radiographic imaging modalities to determine the different influences on knee alignment between the supine position and the single leg stance position. The knee alignment tends to more varus alignment in a single leg stance position.

1. Subgroup analysis

The first subgroup (varus knees only) consisted of six studies[12,22,31,32]. Twelve studies formed the second subgroup (mixed population of varus and valgus knees)[5,21,23,24,25,26,27,28,29.] Studies which only included valgus knees were not found. Therefore, a third subgroup could not be defined.

In subgroup one the mean difference in HKA comparing single versus double leg weight bearing conditions was 1,76° (95% CI (-0,76; 4,30), p= 0,0723). The mean difference in HKA comparing supine versus double leg position was 2,16° (95% CI (-4,64; 8,96), p=0,1546). When comparing supine position and single leg stance a mean difference in HKA of 2,55° (95% CI (-5,11; 10,21), p= 0,1476) was found in subgroup one.

In the second subgroup only supine versus double leg weightbearing position could be investigated and a mean HKA difference of 1,69° (95% CI (1,93; 2,2), p<0,001) was found.

The difference between both subgroup regarding the overall change of HKA from supine position to double leg stance was 0,46° (95% CI (-1,73; 0,81), p= 0,4427).

## Discussion

### Main results

The most important result of this systematic review after analysis of pooled data was that joint deformities in the coronal plane become more pronounced in increasing weight-bearing positions.

The HKA-angle measured in a double leg stance position was 1,76° more varus in comparison to the supine position. In a single leg stance position, the HKA-angle was 1.43° more varus compared to a double leg stance position and 2,08° more varus compared to a supine position (see fig. 2)

Fig2.: The differences in HKA-angle between different weight-bearing positions.

### Literature comparison

Thus, the amount of weight-bearing determines the discrepancies in mechanical axis deviation between weight-bearing and non-weight-bearing conditions. It demonstrates the potential influence of weight-bearing, which is especially relevant in patients with a high body mass index (BMI)[3]. All these findings can be explained by an increasing load during stance phase, which leads to a greater ground reaction force[11]. The ground reaction force passes medial to the joint center, creating an adduction moment that forces the knee into varus.

Interestingly, this trend towards a more varus alignment in the standing position occurs in both asymptomatic and osteoarthritic native knees, as well as in prosthetic knees[4,22,25,26,37,38]. This might suggest that soft tissue restraints might be more important contributors to weight-bearing alignment than rigid bony or prosthetic architecture. Preoperative differences between full length radiographs and computer navigation measurements were significantly higher when mediolateral instability was present as well as with increasing age[24]. This statement is further supported by the difference in joint line convergence angle (JLCA) between supine and standing radiographs, as well as between double leg stance and single leg stances whereby the JLCA increases as a result of the dynamic effects of weight-bearing[30,31,39,40]. The increase in JLCA corresponds to laxity of the lateral soft tissues, which is aggravated by the varus deformity as seen in double and triple varus knees[13,23,36,42]. Patients with a mechanical axis deviation > 2cm or JLCA >3° showed an even higher likelihood of those discrepancies[40]. Knee joints with varus malalignment can thus open laterally, especially with weight-bearing, creating a larger magnitude of mechanical axis deviation than can be accounted for the skeletal deformities alone[40,41].

### Clinical relevance

Knee surgeons who aim to restore the constitutional alignment of their patients instead of aiming to a neutral (0°) alignment, need to be aware of this difference. If a surgeon decides, based on the pre-op double leg stance full-length X-ray to plan the prosthesis to create a 3° varus alignment and executes this plan through navigation-assisted surgery, the end result will involve additional varus. Outliers associated herewith come with a risk of inferior surgical outcomes[2].

However, the weight-bearing increase in coronal alignment deformity is expected to be reduced in post-arthroplasty knees compared to the 1.76° we reported in this study based on non-replaced knees. This can be explained by (1) the increased stiffness of polyethylene compared to cartilage and (2) arthroplasty-induced alterations in the stresses and strains of the soft-tissue stabilizers of the knee and their further response to the increased loading associated with weight-bearing conditions. This is in line with the findings of Willcox et al who suggested that the difference in deformity induced by weight-bearing might be less after implantation[5]. Other studies also mention a more pronounced varus alignment when radiographs were taken at 1 year rather than 6 weeks postoperatively[4]. This could be explained by the fact that patients were still unable to fully weight bear on the affected limb in the early post-operative period[43].

### Limitations

There are some limitations to our review. First of all, the 5-point Oxford Quality rating scale was used to review the included studies. Despite this being the recommended method, the obtained scores were low (0-1/5) because none of the included studies were randomized or double blinded which is inherent to the study design. On the other hand, the studies obtained by the literature search were reviewed by two separate authors using the CONSORT checklist to obtain an adequate quality assessment[16].

Furthermore, the number of included studies in the pooled data analysis is relatively small. In addition, the majority of included studies were comprised of small numbers of patients. This might explain why the results of our meta-analysis did not always reach a level of significance. Studies were classified according to weight-bearing status, medical imaging system used and the knee alignment. A majority of the included studies (12/18) investigated a mixed population of varus and valgus knees. In those studies, a significant varus increase of 1,69° was mentioned when patients changed from a supine to a double leg stance position. In this weight-bearing changes only 2 studies were included which used only varus knees (mean difference in HKA of 2,16°). Due to the small number of these studies, the obtained difference of 0,46° between the varus subgroup and the mixed subgroup was not statistically significant (p= 0,44). As deformity increases with loading, the pre-existing valgus knees will become more valgus with loading. It could declare why the mixed subgroup seems to have less pronounced alignment changes compared to studies which only included varus knees. Thus, our finding of an overall change in HKA of 1,76° more varus in double leg stance in comparison to a supine position might be even an underestimation. Until now, it is unclear how the degree and direction of the deformity determines the effect of weight-bearing positions. Therefore, further research is recommended.

Furthermore, 73 percent of the studies included were based on end-stage OA patients. Therefore, the influence of weight-bearing conditions on knee alignment in asymptomatic versus osteoarthritic versus prosthetic knees could not be determined. Future research is therefore required to define possible differences between these patient populations.

## Conclusion

The overall knee alignment is influenced by the weight-bearing status. Coronal deformity increases with weightbearing loading from supine to double-leg and to single-leg stances. The mean difference between supine and double leg-stance is 1.76°, and the mean difference between double-leg stance and single-stance amounts to 1.43°.

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