


The relationship between constitutional alignment and varus osteoarthritis of the knee

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Abstract

Purpose The role of neutral alignment in total knee arthroplasty (TKA) on short- and long-term outcomes has become controversial. Based on the concept of constitutional varus, it has been suggested that under-correction in TKA in a varus osteoarthritis (OA) population might lead to better clinical outcomes. However, it is still unknown what the relationship between constitutional varus and the development of end-stage OA is. The goal of this study was to analyse the contribution of constitutional varus in a medial OA population and to define a correlation between the constitutional alignment and end-stage varus OA.

Methods Based on full-length radiographs, corrected for the intra-articular deformity of the knee, of 315 patients with unilateral end-stage medial OA of the knee (Charnley type A), a correlation in the coronal plane was made between medial end-stage OA and the contralateral non-arthritis side.

Results With increasing varus alignment in the arthritic limb, the physiologic limb alignment also became more varus. The proportion of constitutional varus rose with increasing overall alignment and was found to be continuous for males. Constitutional varus was three times higher in men when the overall arthritic alignment was greater more than 6° varus.

Conclusion Constitutional varus significantly contributes to varus osteoarthritis and was found to be higher than in the general population.

Level of evidence III.

Keywords Coronal plane alignment · Constitutional varus · Knee · Osteoarthritis · Varus

Introduction

Restoration of the mechanical axis to neutral in the frontal plane has been considered the standard of care in total knee arthroplasty (TKA), with evidence showing it to be a prerequisite for successful long-term outcomes [3, 20, 35]. Biomechanical, retrieval, cadaver, and finite element studies have all supported neutral alignment after TKA, demonstrating lower stress, loading, and polyethylene wear compared to varus alignment [1, 12, 13, 15, 17, 21, 24, 29, 33].

However, the role of neutral alignment on short- and long-term outcomes has become controversial, as the literature shows no difference in revision rates between a neutrally aligned (within $\pm 3^\circ$) TKA and “outlier” varus- and valgus-aligned TKAs [4, 16, 23, 25, 30]. This has been further supported by data of Miller et al. who compared static and dynamic loading of the knee in TKA patients. They reported that dynamic equal mediolateral joint loading is not correlated with a neutrally mechanically aligned knee, indicating that frontal plane alignment is only one of the contributing factors to joint loading [26]. Furthermore, a recent study by Vanlommel et al. [36] showed superior clinical outcome scores in under-corrected TKAs (3° – 6° varus) in a varus osteoarthritic (OA) population. It has been questioned whether these results might be related to the fact that part of this medial OA population has so-called constitutional varus.

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Constitutional varus, a physiologic mechanical axis of 3° varus or more, was recently described by Bellemans et al. [2]. While previous alignment reports provided data that the overall mechanical axis in the general population is 1° – 1.3° varus [6, 10, 27], Bellemans found that in a general healthy population, 32 % of males and 17 % of females had constitutional varus. It has been suggested that varus alignment is one of the main determinants in developing medial OA [19, 34]. If this population presented with end-stage medial OA, correcting the alignment to neutral when performing a TKA would result in a significant anatomy alteration and potentially decreased patient satisfaction due to these changes in biomechanics in different planes [22]. Unfortunately, some of the data suggesting varus alignment is a risk factor for OA examine incidence in end-stage cases without considering constitutional alignment [19].

It is unknown whether there is a higher incidence of constitutional varus in medial OA patients, and it remains unknown what the relationship between physiologic alignment and end-stage varus OA is [38]. This information might be of importance regarding the placement of physiologic TKAs. The goal of this study is to analyse the contribution of constitutional varus in a medial OA population and to define a correlation between the constitutional alignment and end-stage varus OA. This study hypothesised that there would be a greater incidence of constitutional varus in patients with greater varus alignment in their arthritic limb.

Materials and methods

Ethics approval was obtained from the institutional research ethics board (The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects, File No. 104928). A clinical database of all arthroplasty patients operated on at our institution was queried for unilateral end-stage OA patients, (Charnley type-A patients), who had a TKA preformed between 2005 and 2014. A total of 1558 patients were identified, and two observers checked for inclusion and exclusion criteria.

The inclusion criteria for the study were patients with unilateral medial end-stage OA (Kellgren–Lawrence grade 4) and a contralateral knee with less than 50 % cartilage loss (Kellgren–Lawrence grade 0–2). The side with end-stage OA was termed the “arthritic limb”, and the contralateral limb was termed the “physiologic limb”. Also required was the presence of full-leg standing radiographs, with antero-posterior, lateral, skyline, and tunnel views of both knees prior to TKA. Exclusion criteria were inflammatory or posttraumatic OA, unicompartmental lateral or patellofemoral end-stage OA, extra-articular deformities of the lower leg, prior surgery of the hip, femur, tibia or ankle changing the mechanical axis, or poor-quality full-leg

standing radiographs. After inclusion and exclusion criteria were met, a total of 315 patients were available for further analysis.

Full-leg standing digital radiographs were available for all included patients and obtained prior to primary TKA as described by Paley et al. [28]. Both limbs (arthritic and physiologic sides) were measured by two independent



Fig. 1 Full leg standing radiograph with angles measured: HKA, CH, CP, PA

examiners for coronal plane mechanical alignment as previously described by Cooke et al. [11], as represented in Fig. 1. Measurements up to 0.01° were taken.

The overall mechanical axis was defined as the hip–knee–ankle (HKA) angle, which was the angle between the femoral and tibial mechanical axes. This was expressed as a deviation from 180° , with a negative value correlating with varus and a positive value with valgus. The femoral mechanical axis was defined as a line from the centre of the femoral head (measured with the use of digital concentric templates) to the centre of the femoral notch. The tibial mechanical axis was defined as a line from the midline between the tibial spines and the mid-point of the talus. The plateau–ankle (PA) angle was defined as the angle between the tibial margin and the tibial mechanical axis. The condylar–hip (CH) angle was defined as the angle of the femoral condylar tangent with respect to the femoral mechanical axis. For both the CH and PA angles, a negative value correlated with varus alignment and a positive value correlated with valgus alignment. The condylar–plateau (CP) angle represents the intra-articular deformity and was defined as the angle between the femoral and tibial joint surfaces. This CP angle represents the soft tissue laxity and has been shown to influence the alignment in a weight-bearing position [31]. Narrowing medially has a negative value (thus contributing to varus alignment), while lateral narrowing correlated with a positive value (thus contributing to valgus alignment). To differentiate between the physiologic and the arthritic limbs, all values addressing the arthritic side were given a subscript “oa” (e.g. HKA_{oa}) and values addressing the physiologic side a subscript “phys” (e.g. HKA_{phys}).

Since the physiologic side included Kellgren–Lawrence grades 0, 1, and 2 OA, the mean CP_{phys} angle of grades 1 and 2 was corrected for the difference to CP_{phys} of grade 0 for each individual. This was performed to better represent the true constitutional alignment of the patient, by eliminating any difference due to OA-induced intra-articular deformity. The correction in CP_{phys} was therefore also applied to adjust the HKA_{phys} , which was alternatively defined as the constitutional mechanical alignment. Similarly on the arthritic side, CP varies greatly due to articular deformity. Several possibilities for correction were examined, including using the measured CP_{oa} , substituting CP_{phys} , and correcting CP to 0° , with HKA_{oa} adjusted accordingly in all cases. The strongest correlation between HKA_{phys} and HKA_{oa} was found with CP corrected to zero ($r^2 = 0.33$, $p < 0.0001$); therefore, this method was used for the HKA_{oa} measurements.

Statistical analysis

The distribution of physiologic alignment (HKA_{phys}) for every 3° of HKA_{oa} was determined and analysed for the general OA population and separately for males and females. The

contribution of constitutional varus in medial OA patients was also determined and specified for gender. A Bland–Altman analysis was performed to determine the limits of agreements (95 % confidence interval) between examiners. The D’Agostino and Pearson omnibus normality test was used to evaluate whether data were normally distributed. Unpaired t-tests were used to compare CH and PA between groups. Linear regression was used to examine trends in distribution.

Results

Of the 315 patients, 49 % of the population were female and 51 % were male. The physiologic knee was graded as a grade 0 OA in 19 patients, grade 1 OA in 105 patients, and grade 2 OA in 189 patients. The mean age (\pm SD) was 61.6 ± 9.9 years in the grade 0 group, 66.5 ± 9.0 years in the grade 1 group, and 67.7 ± 9.0 years in the grade 2 group. The mean CP_{phys} before correction was $-0.43^\circ \pm 1.10^\circ$ for grade 0, $-0.96^\circ \pm 1.10^\circ$ for grade 1, and $-1.96^\circ \pm 1.20^\circ$ for grade 2. There was no difference in PA angle (n.s.) or CH angle (n.s.) between grades 0 and 1 and the grade 2 OA group (Table 1).

The limits of agreement (95 % CI) between the two examiners for the overall mechanical alignment—HKA—measurements were -0.19° to 0.24° . Almost all patients with an HKA_{oa} of $0 \pm 3^\circ$ had an HKA_{phys} also within $0 \pm 3^\circ$ (Fig. 2), including 91 % of patients up to 3° valgus and 88 % of patients up to 3° varus. With increasing varus alignment in the arthritic limb, the physiologic limb alignment also became more varus. The HKA_{phys} was within $3^\circ \pm 3^\circ$ varus for 81 % of patients with HKA_{oa} alignment of 3° – 6° varus, for 77 % of patients with HKA_{oa} alignment of 6° – 9° varus, and for 80 % of patients with HKA_{oa} alignment of 9° – 12° varus. The HKA_{phys} was within $6^\circ \pm 3^\circ$ varus for all patients with HKA_{oa} alignment of 12° – 15° varus. None of the patients had a constitutional varus of more than 9° , with 8.47° being the highest value.

Overall, 46 % of male patients and 23 % of female patients with $HKA_{oa} > 0^\circ$ varus had constitutional varus ($HKA_{phys} \geq 3^\circ$ varus). The proportion with constitutional varus rose with increasing HKA_{oa} (Fig. 3). The rise was continuous for males, eventually reaching 100 % for patients with HKA_{oa} alignment of 12° – 15° varus

Table 1 CH and PA angle for grades 0, 1, and 2 OA at the physiologic side

	CH (mean \pm SD)	PA (mean \pm SD)
Grades 0 and 1	$1.7^\circ \pm 1.8^\circ$	$-3.5^\circ \pm 2.0^\circ$
Grade 2	$1.7^\circ \pm 1.8^\circ$	$-3.0^\circ \pm 2.1^\circ$
<i>p</i> value	0.78	0.07

Fig. 2 Distribution of every 3° N-HKA_{phys} for every 3° N-HKA_{oa}

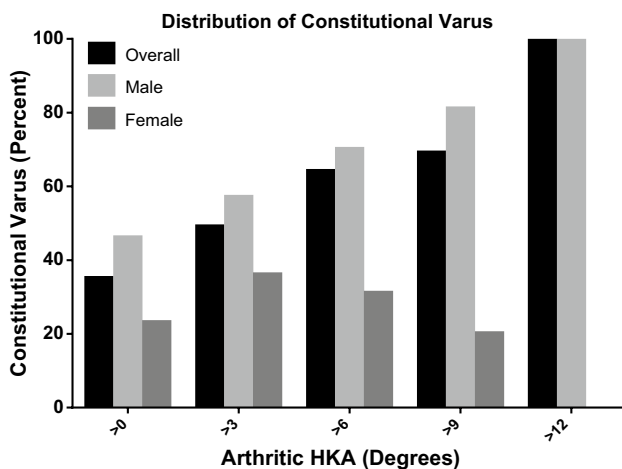
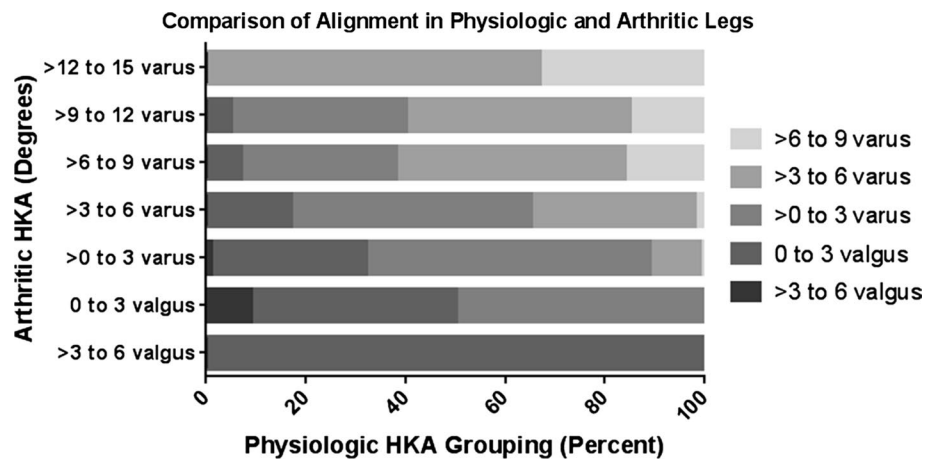


Fig. 3 Contribution of constitutional varus in the general population, males, and females for every 3° of progressive varus N-HKA_{oa}

($r^2 = 0.99$, $p = 0.0005$). For females, the proportion with constitutional varus rose and then fell (n.s.). In every group, more men than women had constitutional varus. However, there were three times greater males ($n = 64$) than females ($n = 23$) with an HKA_{oa} alignment of $>6^\circ$ varus. This pattern of the proportion of patients with constitutional varus was again found within specific ranges of HKA_{oa} (Fig. 4), with a continuous rise for males ($r^2 = 0.97$, $p = 0.002$) and a rise then fall for females (n.s.).

Discussion

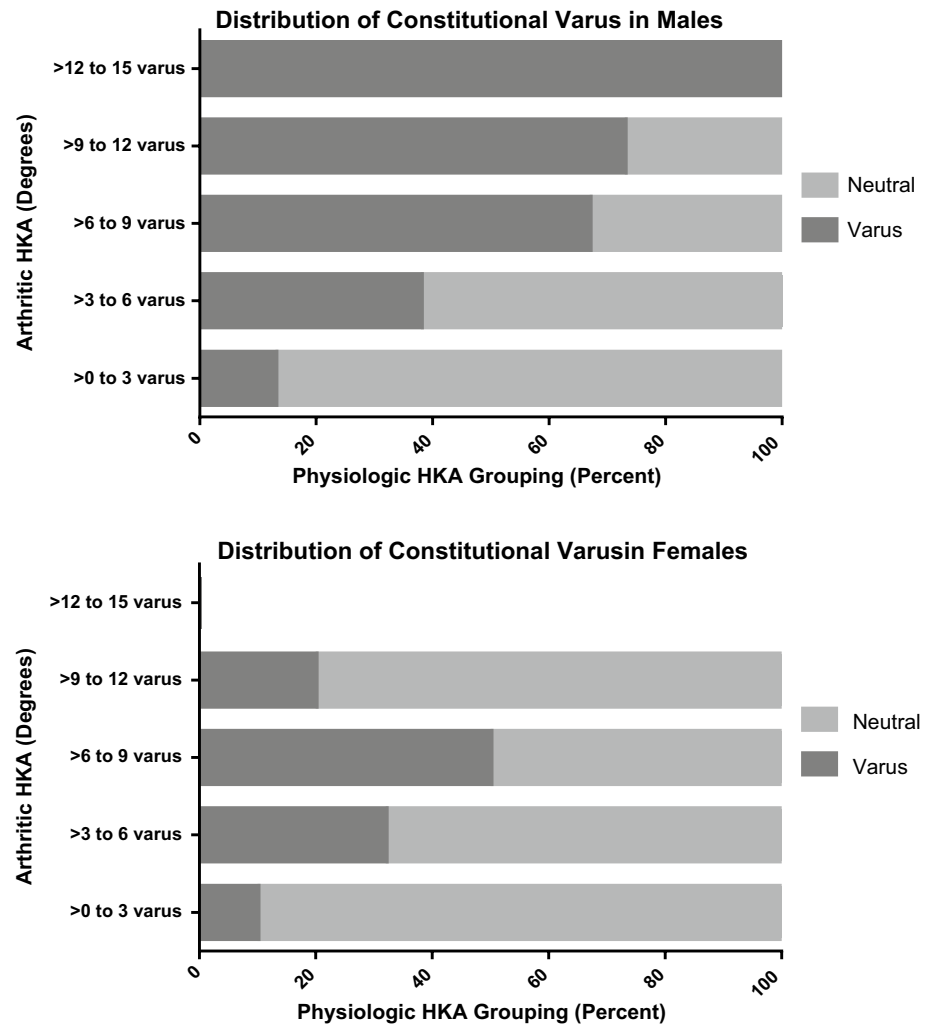
The present study is the first to describe a correlation between primary varus OA and physiologic alignment. The most important finding of our study is that the contribution of constitutional varus in a medial OA population is higher than in the general population and that it increases

with progressively more varus arthritic knees. This trend was stronger for male patients than for females, potentially due to relatively lower numbers of females with more varus-aligned arthritic knees in the study. Considering the overall population, patients with constitutional varus may be more at risk to develop end-stage OA and may therefore be a “high target” for future realignment procedures or arthroplasty.

The results of this study further open the debate on frontal plane alignment in TKA. While numerous studies [3, 14, 32] on survivorship describe excellent outcomes when the frontal plane axis was corrected to neutral alignment ($0^\circ \pm 3^\circ$), recent reports have challenged this long-standing “gold standard” [4, 16, 23, 25, 30]. Motivation for these challenges stems from the finding that patient satisfaction after TKA is lower than after total hip arthroplasty [5]. Recently, Vanlommel et al. demonstrated that superior clinical outcomes were achieved if the TKA was left “under-corrected” (i.e. in 3° – 6° of varus) in a varus OA population. In the present study, a large portion of patients with an alignment of $>0^\circ$ varus in their arthritic limb had constitutional varus. However, only a minority of these patients had a physiologic alignment $>6^\circ$ varus.

This distribution could provide an opportunity for defining a more physiologic target for TKA placement in patients with end-stage OA and varus frontal plane alignment. Most patients with an arthritic limb alignment of $0^\circ \pm 3^\circ$ also had neutral ($0^\circ \pm 3^\circ$) physiologic limb alignment. For patients with $>3^\circ$ – 12° varus arthritic limb alignment, the constitutional alignment was $3^\circ \pm 3^\circ$ varus in approximately 80 % of the population, and those with an arthritic limb alignment of $>12^\circ$ varus all had constitutional varus of $6^\circ \pm 3^\circ$. Taking into account the possible error in placement of TKA, a target of 0° for an HKA_{oa} of $0^\circ \pm 3^\circ$ and a target of 3° varus for an HKA_{oa} of $>3^\circ$ varus might reconstruct the physiologic alignment as close as possible. In some cases, computer-assisted surgery might be necessary to achieve these

Fig. 4 Contribution of constitutional varus in the general population, males, and females for every 3° of N-HKA_{oa}



goals [7, 8]. These targets of correction will require further analysis in future descriptive clinical outcome studies in varus OA patients undergoing TKA, especially regarding whether this “under-correction” undermines survivorship. Given the high incidence of constitutional varus patients found in this study, and the difference between males and females, studies describing outcomes after TKA would be prudent to specify varus, neutral, or valgus OA and subdivide outcomes for women and men.

This study has its limitations. The use of full-leg radiographs has been showed to possibly have rotational errors and therefore might reduce the accuracy of measurements [9, 11, 37]. The error of measurements was reduced in our study by using two independent observers, and the inter-observer variability was shown to be low. Secondly, the contralateral non-arthritic side was used as the control population, without evidence that the contralateral side has the same physiologic alignment as the OA side. Ideally, patients would be followed longitudinally with full-leg radiographs in order to understand the natural course

of physiologic alignment. However, this is obviously difficult to accomplish. Similarly, most of the patients presenting with primary OA have bilateral arthritic changes, and with low numbers of patients with grade 0 OA in the physiologic limb, patients with grade 1 OA (possible narrowing of the joint space) and grade 2 OA (with less than 50 % cartilage loss) of their physiologic limbs were also included. There was no difference in CH and PA angle between grades 0 and 1 versus grade 2, which suggests the difference in alignment between grades 0 and 2 is minor. A correction for CP was performed in the physiologic limb for grades 1 and 2 to equal the mean CP in the grade 0 group and corrected CP in the arthritic limb to 0°, with corresponding adjustments to HKA in both the physiologic and arthritic groups. This served to minimise the effects of intra-articular deformity and medial bony wear at the tibial and femoral side on HKA, which have a wide variability. Finally, compared to the general population having constitutional varus as described by Bellemans et al., the present study population was significantly older with a mean age of

66.9 years. However, knee joint orientation has previously been described in elderly up to 60 years [6, 18].

Correlation of unilateral arthritic knees to the unaffected, physiologically aligned knee using full-leg radiographs indicates that it may be possible to understand the patient's physiologic, pre-arthritic coronal plane alignment. This research may provide important information regarding the placement of physiologic TKAs and direct future research questions.

Conclusion

Constitutional varus significantly contributes to varus osteoarthritis.

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