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ORIGINAL STUDY

Coronal alignment in osteoarthritic knees, does it change in flexion?

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Changes in coronal alignment in osteoarthritic knees evolving from extension to flexion remain poorly studied.

Using an imageless computer-navigation system (Stryker©) we prospectively collected measurements of dynamic coronal pre-implant alignment during primary total knee arthroplasty. Coronal alignment of the osteoarthritic knee was determined at maximal extension and 90° flexion. Measurements were subgrouped as varus (≤-3°), neutral (>-3°, <+3°) or valgus (≥+3°). Of 545 osteoarthritic knees (347 females), coronal alignment in extension was 261 (48%) varus, 197 (36%) neutral and 87 (16%) valgus. Varus extension alignment was more common in male versus female knees (p< .0001). Valgus extension alignment was more common in female versus male knees (p= .002). In flexion, 174 (66%) of varus knees remained varus. Coronal alignment remained unchanged (within +3° ; -3°) in flexion versus extension in approximately half of the OA knees observed. This insight into a changing coronal deformity might contribute to a better understanding of osteoarthritic knee behaviour.

Keywords : Total knee arthroplasty ; coronal alignment ; computer assisted navigation ; kinematics ; deformity ; osteoarthritis.

INTRODUCTION

Osteoarthritis (OA) of the knee is a common pathology affecting 27.4% of the population between the ages of 65-69 and increasing with age *(9)*. It affects all structures within the knee joint causing articular cartilage loss, bony remodelling, capsular stretching and weakness of periarticular muscles. All of these reasons may contribute to a malalignment of the OA knee *(8)*. A total knee arthroplasty (TKA) is considered a safe and reliable treatment *(14)*. Increasing knowledge concerning the kinematics and alignment in the OA knee might contribute during this procedure.

Maintaining a neutral coronal alignment after total knee arthroplasty resulting in a straight leg was historically considered the prime surgical goal. A neutral mechanical axis (0° ± 3°) was regarded as correctly aligned whereas outliers (<-3°, >3°) were malaligned *(14,16)*. Although no anatomical

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or biomechanical axes are restored it is considered mechanically more stable resulting in higher survivability of the components as malalignment and malpositioning of the components may lead to an early revision *(6,19,27,28,36)*. However, some studies contradict these hypotheses and didn't notice a better survival in a 15-year postoperative follow-up after successfully restoring a mechanical axis of 0° (SD 3°) *(2,25)*.

Coronal plane deformities are defined as a varus or valgus angle. Traditionally the coronal alignment is measured using an AP standing radiograph in maximal extension. Although these radiographic images offer a clear view onto the extension alignment we have little information as to how this alignment evolves proceeding to 90° of flexion. Furthermore, little research has been conducted concerning the coronal flexion alignment in osteoarthritic knees nor about its clinical relevance or the relation between both the extension and flexion (dynamic) coronal alignment.

Scientific data concerning the flexion alignment has proven to be difficult to gather. Research consisted mainly of biomechanical cadaver studies containing small populations. Recently Maderbach et al. witnessed a mean extension varus of 3.3° evolving into a mean flexion valgus of 0.6° in 10 healthy cadaveric knees. Although tibial internal rotation was included in these studies a great interspecimen variability was acknowledged *(10,20,29)*.

Increasing use of computer navigation software offers the possibility to collect new data concerning the kinematics involved in the knee-motion. The use of navigation in TKA has proven useful in correct placement of the prosthesis components and reducing the amount of severe varus/valgus outliers *(3,11,22,30,31,35)*. Several authors published better functional outcome and fewer complications comparing navigation-assisted arthroplasty to conventional arthroplasty *(4,21,24,32)*.

During routine use of computer-assisted TKA we noticed the extension deformities in the coronal plane were not consistent during flexion. We conducted a study to observe the dynamic behaviour of the coronal alignment evolving from full extension to 90°of flexion. Secondly, we attempted to find a correlation between the flexion and the extension deformity.

MATERIAL AND METHODS

In 2004 one surgeon (GL) started using computer navigation as a routine procedure for TKA at our institute. Between June 2011 and April 2016 intra-operative data was saved of all patients undergoing a navigated primary TKA for the purpose of this study. All OA knees were included without making a distinction between preoperative functional outcome, grade of OA, deformity, age or gender. We gathered data of five hundred and forty-five OA knees (498 patients, mean (±SD) age : 71.1 years ±9.3, 347 (57%) female knees). We examined the coronal alignment of the OA knee before performing any bony cuts or ligamentous releases using the Hip-Knee-Ankle-angle (HKA angle) at maximum extension and at 90° of flexion. The HKA angle was defined as the angle formed by the mechanical femoral axis and the mechanical tibial axis. The HKA angle was expressed as a deviation from 0° with a negative value for varus and positive value for valgus. It was extracted using an individual data table and curve created by the navigation software for each knee during surgery (Figure 1 & Table I). The minimal measurable difference by this software was 0.5°.

Surgical technique

All 545 total knee arthroplasties were performed by one surgeon (GL), using a tourniquetless medial subvastus approach. Two femoral navigation pins were drilled into the anterior-medial side of the distal femur and two pins were drilled into the proximal tibia, distal to the tibial tubercle. After pin-insertion navigation trackers were attached and tightly locked onto these pins to prevent any further tracker movement. We used a surgical imageless computer-navigation system to gather the data. (Navigation System II – precision Knee module, Stryker Orthopaedics, Mahwah, New Jersey). This navigation device produces a very high linear accuracy and high trueness of data acquired *(7)*. Using a pointer anatomical

Table I. — Example of standard data capture

+	-	min						max
Flexion	Hyperextension	+1.5°	+0.0°	+30.0°	+45.0°	+60.0°	+90.0°	+93.0°
Valgus	Varus	-4.0°	-3.0°	-3.5°	-3.5°	-0.5°	+1.5°	+1.5°
Internal	External	-11.0°	-10.5°	+0.0°	+0.5°	+2.0°	+4.0°	+4.5°

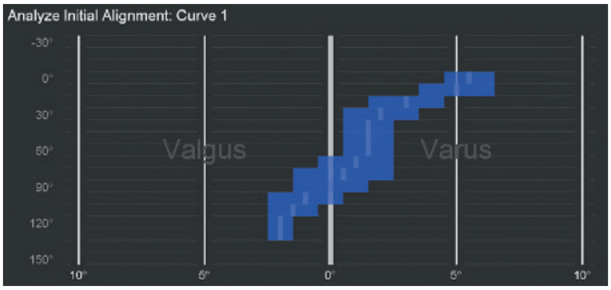

Figure 1. — Example of standard data capture of the alignment table and curve as provided by the software.

reference points are established and digitized in a routine procedure. The hip centre is acquisitioned by rotating the femur around this centre. The knee rotation axis is defined by the mean of both AP and transepicondylar axes. The ankle centre is calculated by dividing the digitized transmalleolar axis according to a ratio of 56% lateral to 44% medial with the inherent navigation system.

The reference axis for the femur is the mechanical femoral axis defined by the digitized hip centre and knee centre, and the reference for the tibia is the mechanical tibial axis defined by the digitized tibia centre and calculated ankle centre. Using Euler decomposition (the XYZ-Rotated method) the varus-valgus angle (HKA angle) is calculated after having already taken the tibial and femoral rotation as well as the flexion angle into account. (Figure 2). Prior to any bone cuts of ligaments releases the knee is manipulated through two cycles of motion from maximum extension to maximum flexion to record the complete pre-implant ROM. By supporting the thigh with one hand and the heel with the other no valgus or varus stress is applied during this motion. Hyperextension as well as flexion contractures are exposed.

All statistical analysis was performed using Microsoft® Excel® 2016 and p-value <0.05 was considered statistically significant. The quantitative variables were described with mean and standard deviation and categorical variables with frequencies and percentages. The Chi-square test was used to assess the relationship between two categorical variables.

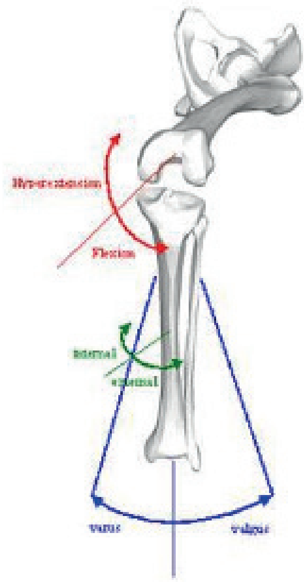

Figure 2. — The HKA angle is determined independent of the flexion and provides accurate data during both flexion and extension.

Table II. — Demographic patient data

	All (n=545)			male (n=198)			Female (n=347)		
	varus	neutral	valgus	varus	neutral	valgus	varus	neutral	valgus
HKA angle 0° flexion (mean)	-6,4	-0,1	5,4	-6,7	-0,2	4,9	-6	-0,02	5,6
HKA angle 90° flexion (mean)	-4,4	-0,9	3,1	-4,3	0,4	1,9	-4,4	-1,3	3,4
age (years)	70,3	70,3	73,1	69,1	70	70,7	70,7	70,5	74,4
Total	261	197	87	126	53	19	135	144	68

RESULTS

We divided 545 knees in three subgroups according to their HKA angle in maximal extension : varus (≤-3°), neutral (>-3°, <3°) or valgus (≥3°). The majority of knees exhibited an extension alignment in varus (n = 263). (Table II) The male cohort presented with significantly more varus aligned knees in extension (63.6%) compared to the female cohort (38.9%) (p< 0,0001). The mean (±SD) HKA angle was more severely varus aligned in males (-3.9° (±2.8°)) compared to females (-1.3° (±2.8°)). Female patients presented with significantly more valgus aligned knees compared to men (p=0.0021). The mean (±SD) difference between the extension

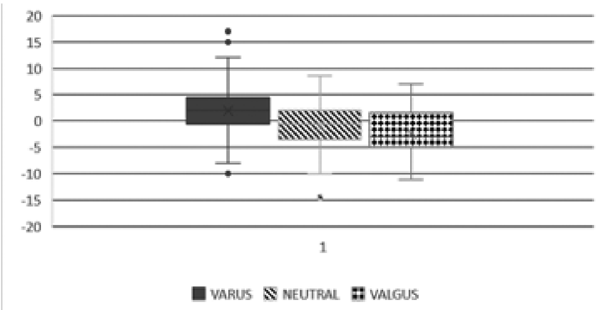

Figure 3. — Boxplot (minimum, Q1, median, Q3, maximum) displaying the difference between the coronal alignment in extension and flexion. A positive value on the Y-axis stands for increasing valgus. A negative value on the Y-axis stands for increasing varus. We notice the deformity decreases in flexion in both valgus and varus.

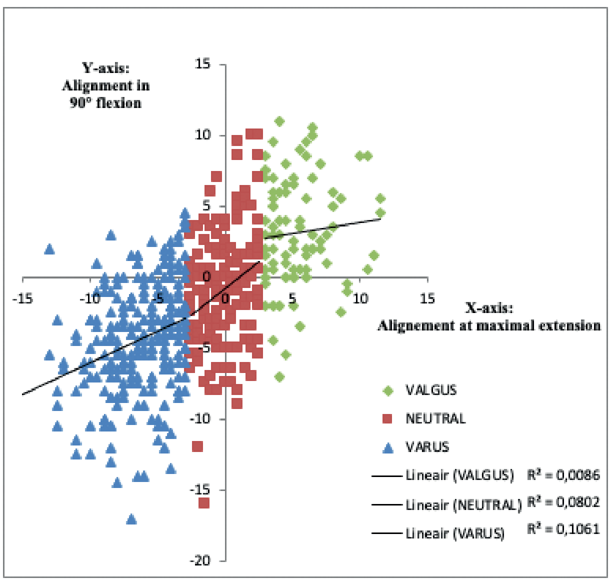

Figure 4. — Scatterplot of the coronal alignment in extension versus flexion. X-axis is positive for extension valgus and negative for extension varus. Y-axis is positive for flexion valgus and negative for flexion varus. Varus is represented in blue, neutral in red and valgus green. Linear trendlines are shown.

and flexion alignment is respectively -1.98° (±4.0°) for varus, -0.77° (±4.0°) for neutral and +2.3° (±4.2°) for valgus with a positive value for increasing valgus or a negative value for increasing varus (Figure 3). Dynamic coronal alignment was unchanged in 27/545 (4.9%) and alternated between varus and valgus in 10/348 (2.9%) AO knees.

Using a scatter plot we derived the relationship between the coronal alignment in maximum extension and 90° flexion (Figure 4). Linear trendlines show highest predictive value (highest R^2-value) for extension varus alignment compared to neutral and valgus. ($R^2 = 0.1061 > R^2 = 0.0802 > R^2 = 0.0086$)

Varus

Mean (±SD) extension varus was -6.3° (±2.8°, ranging from -3° to -19°) evolving into a mean (±SD) flexion alignment of -4.4° (±3.9°, ranging from -17° to 4.5°). The Sex-ratio M/F was 126/135.

Neutral

Mean (±SD) extension alignment was -0.1° (±1.5°, ranging from -2.5° to 2.5°) evolving into a mean flexion (±SD) alignment of -0.7° (±4.1°, ranging from -16° to 10°). Sex-ratio M/F was 53/144

Valgus

Mean (±SD) extension alignment was 5.39° (±2.2°, ranging from 11.5° to 3°) and evolved to a mean flexion (±SD) valgus of 3.86° flexion (±3.8°, ranging from -17° to 11°).

DISCUSSION

Alignment

OA of the knee is a complex disease. Soft tissue contractures of the medial collateral ligament and posteromedial capsule as well as tibial and femoral bone loss contributing to angular deformities are observed. A varus aligned knee expresses mainly postero-medial tibial bone loss contributing to an apparent varus deformity in both extension and flexion. In valgus aligned OA knees both femoral and tibial bone loss are present *(15)*. If we presume that cartilage loss in varus knees is predominantly expressed in the medial tibial plateau this coronal deformity would be similar in extension as well as in 90° of flexion. Our findings seem match these presumptions showing a higher prevalence of flexion varus if the knee exhibits varus alignment in extension. This trend is clearly illustrated in the scatterplot by a majority of triangles in the left lower quadrant (Figure 4). Furthermore, severe extension varus (>10°) remained varus in flexion with almost certainty (96.5%). A recent study by Tan confirms this results although they chose a varus angle of >20° as cut-off *(31)*. However, Johnson, using video fluoroscopy, found that extension and early flexion (0° - 40°) in varus AO knees corresponds with a high tibial and femoral cartilage loss. Also, lateral tibial cartilage loss was significantly higher compared to medial cartilage loss in deep flexion angles (>40°) *(23)*. Cartilage wear patterns in osteoarthritic knees are complex and variable. Predicting certain wear patterns based on different coronal deformities might not be a straightforward as stated before *(15)*.

In case of neutral or valgus extension alignment few predictions about the flexion alignment can be made. Approximately half of extension valgus aligned AO knees remained valgus and half of the extension neutral aligned OA knees remained neutral. Low predictive value is confirmed by the trendlines and accompanying low R^2-values (figure 4). Both valgus and neutral knees showed a slight tendency toward varus going from extension into flexion. This trend is more strongly present in valgus knees (figure 3).

We noticed the deformity in both varus and valgus groups reduces in flexion and thus an extension varus or valgus will on average expresses a smaller deformity in flexion. Only 2.9% (10/348) of all valgus and varus aligned knees alternated between valgus and varus compared to 14.1% as published by Deep et al. *(5)*.

We encountered significantly more extension varus knees in the male population and significantly more extension valgus knees in the female population. These data correspond with recent articles by Bellemans et al. that contest neutral alignment as surgical goal introducing the concept of a constitutional varus presenting with a mean HKA angle exceeding 3°of varus present in 32% of healthy male knees *(1,13,34)*.

We do not intent to discuss the 'ligament-balancing versus neutral alignment' or the different surgical techniques nor advocate the routine use of computer navigation. Our goal was to observe and analyse the coronal alignment in 90° of flexion.

Radiographic imaging

We believe one of the reasons for the lack in research concerning the coronal flexion alignment may be the difficulties in gathering reproducible data. Preoperative radiographic imaging often consists of no more than a simple short-leg standing radiograph showing only the knee joint. In 1988 Peterson and Enge demonstrated that the difference in anatomical femoral-tibial angle between short- and long leg radiographic AP images averaged 1.4° *(26)*. Moreover, the coronal flexion alignment is not measurable on AP-radiographs in 90° of flexion because of a lack of information concerning the femoral rotation. Using computer navigation, we did not need to perform a preoperative CT-scan as is recommended to determine the rotation of the distal femur in the axial plane *(33)*.

Limitations

We acknowledge some limitations as well as strengths to this study. We prospectively collected and retrospectively analysed measurements of dynamic coronal alignment without incorporating any pre-, intra- or postoperative factors such as grade of OA, coronal angle of deformity, flexion contractures, implant position, postoperative alignment or functional outcome. We did not include the tibial rotation due to a lack of available data and high inter-individual variation *(20,29)*.

The navigation software is directly dependable on the anatomic reference points as entered by the surgeon. A thorough knowledge of the anatomical reference points is essential. Incorrect input of the digitized reference points results in faulty measurements and a failed digital reconstruction. Likewise, a change in navigational environment (movement of pins or rigid bodies) leads to a flawed digital reconstruction and renders the computer navigation obsolete. Klein and others acknowledged some limitations such as tissue release as a result of exposure prior to measurements and intra-observer errors. *(12,17,18)*. However, we minimized the variability in kinematic registration and anatomical landmark recognition by allowing only one experienced surgeon to perform the surgical procedure.

CONCLUSION

Coronal alignment remained unchanged (within +3° ; -3°) in flexion versus extension in only half of the OA knees observed. Accordingly, the coronal flexion alignment cannot be extrapolated from the coronal extension alignment. This insight into a changing coronal deformity might contribute to a better understanding of osteoarthritic knee behaviour. Further studies including prognostic value and functional outcome are warranted.

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