Editorial

Frontal Plane Knee Alignment: A Call for Standardized Measurement



Evaluations of knee alignment are useful in the diagnosis of arthritic conditions affecting the knee joint, serving also as a guide for conservative management and surgical planning[1-5]. They are also fundamental to various aspects of musculoskeletal research. Recently, there has been great interest in frontal plane alignment measures related to the pathogenesis of knee osteoarthritis (OA)[6,7]. Several approaches have been proposed over the years to describe and measure alignment[1-5,8-10], but the differences between them have made it difficult to compare or correlate the results of independent studies. Toward a standard approach to the measurement and reporting of alignment data that may be equally applicable to clinicians and researchers, we discuss a system of measurements based on geometric analysis of the femur, tibia, and knee joint surfaces. We also discuss a standardized methodology for measurement and computation of these parameters.

PRINCIPLES AND MEASUREMENTS OF ALIGNMENT

From the anatomical and functional perspective, the orientation of the femur and tibia at the knee is best described in terms of the bones' mechanical axes. The orientation of these axes reflects alignment in stance, which may be neutral, varus (bowlegged), or valgus (knock-kneed) (Figure 1).

The mechanical axis of the femur (FM) is located as a line from the center of the femoral head running distally to the mid-condylar point between the cruciate ligaments[11]. In the case of the tibia, the mechanical axis (TM) is a line from the center of the tibial plateau (interspinous intercruciate midpoint) extending distally to the center of the tibial plafond[12] (Figure 2). The angle between these 2 axes is the hip-knee-ankle (HKA) angle[1,13]. In the neutrally aligned limb the HKA angle approaches 180°. At this point FM and TM are colinear, pass through the knee center, and are coincident with the load-bearing axis, which is the line of ground reaction force passing from the ankle to the hip[1,13] (Figure 1B). In varus the knee center is lateral to the load-bearing axis (Figure 1A), whereas in valgus the knee center is displaced medially[13,14] (Figure 1C). As a convention the HKA angle may be expressed as its angular deviation from 180° (i.e., HKA = 0° in neutral alignment). Varus deviations are negative and valgus deviations are positive. Our choice of varus as a negative value and valgus as positive was based on the general observations of a more serious problem of loading and damage in the varus knee.

Limb alignment (HKA) depends both on long bone geometry and on the geometry of the articulating surfaces of the femur and tibia[1]. In the course of knee arthritis, changes of alignment are usually ascribed to changes in the articulating geometry. Typically, focal erosion in the medial compartment leads to narrowing that, under load, displaces the knee center laterally (varus deformity; Figure 1A). Similarly, narrowing of the lateral compartment imparts medial knee displacement (valgus deformity; Figure 1C). But, on occasion, deformity of the femur and/or tibia also influences alignment. To understand the basis for alignment (and change thereof in the course of disease) it is crucial to be able to measure and document articular surface relationships and define limb bone morphology. Based on simple geometric analysis the following elements usefully define the geometry of the tibial and femoral surfaces and the angle between them when loaded in stance[1,13] (Figure 2).

1. Condylar-hip (CH): the angle of the femoral condylar tangent with respect to the FM axis;
2. Plateau-ankle (PA): the angle between the tibial margin tangent and the TM axis;
3. Condylar-plateau (CP): the angle between the femoral and tibial joint surface tangents.

Since HKA is expressed as degrees of deviation from 180°, CH and PA angles are expressed as degrees of deviation from 90°, negative for varus and positive for valgus. A joint space angle (CP) that narrows medially is designated varus (–) and laterally valgus (+). When these conventions are observed, the following relationship applies[1,13]:

$$HKA = CH + PA + CP$$

Surveys[8,9,13,15,16] have been made in attempts to establish "normal" alignment values in populations without arthritis. The results shown in Table 1 are based on measurements of mechanical axial alignment, depicted as the HKA angle. As might be expected, the data indicate that the average for

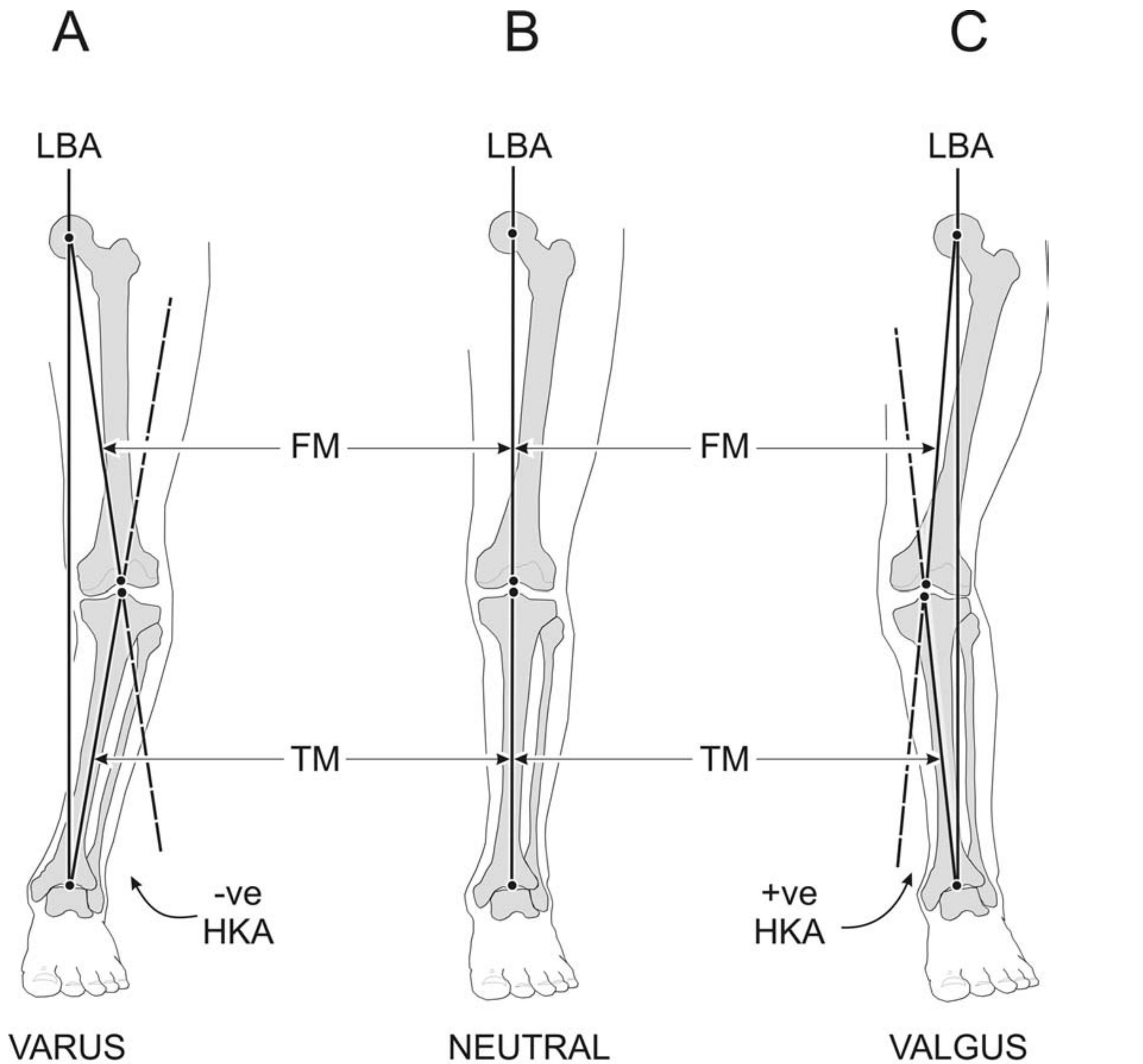

Figure 1. Common frontal plane lower limb alignment patterns. A. Varus alignment: knee center is lateral to the LBA (HKA is negative). B. Neutral alignment: knee center is located on the LBA (HKA = 0°); femoral and tibial mechanical axes are colinear. C. Valgus alignment: knee center is medial to the LBA (HKA is positive). LBA: load-bearing axis, HKA: hip-knee-ankle angle, FM: femoral mechanical axis, TM: tibial mechanical axis.

nonarthritic alignment is close to neutral (–1.0° to –1.3°), although the large standard deviations denote that significant numbers support a pronounced varus or valgus alignment, possibly a predisposing factor for arthritis in later years.

METHODOLOGY

Limb alignment and joint angular data are ideally obtained using long radiographs for measurement. Accuracy will be further enhanced by use of standardized systems, especially for positioning of the subjects. Commonly, however, femorotibial alignment is measured from short views of the knee, which may only define limited aspects of the bones' anatomical axes[17-19]. The femoral anatomical (shaft) (FS) axis may be a reasonable approximation of the FM axis, since these axes are offset from each other by only 5° or so, with small variance[11,17]. However, anatomic axes located on short views poorly predict mechanical axes, especially with proximal or distal bone deformity[16,20]. Thus, in the presence of proximal coxa vara or distal tibia vara (developmental or acquired) a varus malalignment may be missed. It is self-evident that the shorter the view of the knee the greater the risk of missed deformity. Currently, the prevalence of such conditions is not well documented, and requires surveys using full-length views[1,20].

To combat error it is critical to consider a standardized approach to image acquisition and data extraction. One approach is to standardize the positioning of subjects by use

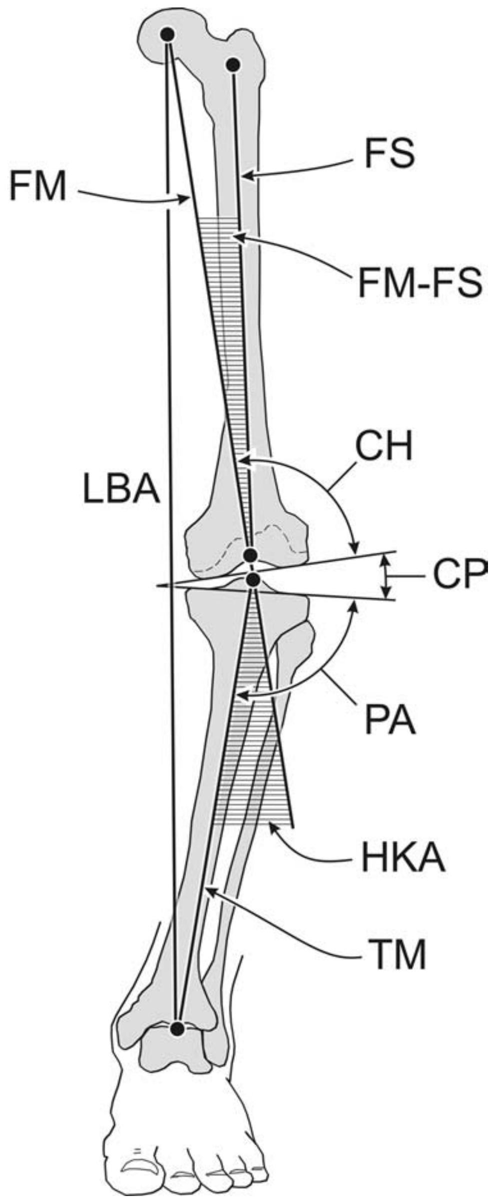

Figure 2. Frontal plane angles in a limb with varus alignment. LBA: load-bearing axis, CH: condylar-hip angle, the angle of the femoral condylar tangent with respect to the femoral mechanical axis; varus negative, valgus positive. For the HKA measured as deviations from 90°. PA: plateau-ankle angle, the angle between the tibial margin tangent and the tibial mechanical axis; varus negative, valgus positive. For the HKA measured as deviations from 90°. CP: condylar-plateau angle: the angle between the femoral and tibial joint surface tangents; narrowing medially, negative, and laterally positive. HKA. Hip-knee-ankle angle: the angle between the femoral and tibial mechanical axes; varus negative, valgus positive. Measured as 180° equaling zero. FM: femoral mechanical axis, TM: tibial mechanical axis, FM-FS: angle between the femoral mechanical axis and the femoral shaft axis.

of a frame, avoiding inaccuracy due to random variation of limb rotation and knee flexion[21,22]. Angles comprising the HKA (i.e., those based on mechanical axes) were measured with less error than similar angles based on anatomic axes[21-23].

Table 1. Frontal plane knee alignment of asymptomatic adults. Hip-knee-ankle (HKA) is the angle between the mechanical axes of the femur and tibia (deviation from 180˚; negative angle denotes varus alignment).

Study	HKA Angle	SD
Moreland[9]	–1.3˚	2.0
Hsu[8]	–1.2˚	2.2
Cooke[16]	–1.0˚	2.8
Chao[15]	–1.2˚	2.2

We have reported a system in which the ankles are located over fixed marks on a rotatable platform and the limbs are then rotated to align the plane of flexion within the sagittal plane; the hips are supported to restrict further movement[1,20-22]. This set-up allows for rotation of the subject (maintaining the position) so as to obtain orthogonal lateral views using a cassette between the knees[1,20].

Errors may also be associated with particular types of deformity. For this reason we have avoided the "patella-ahead" alignment of the limbs during set-up, which may actually produce mal-rotation, since patellar malalignment is common[24]. Similarly, positioning so that the posterior profiles of the condyles are coincident is prone to error because of frequent condylar asymmetry[11,13]. Another feature relevant to alignment is knee subluxation (frontal plane), since it may influence the measured HKA angle. This association is not well documented, but in any case compensation may be made by measuring the displacement (lateral or medial) of the mid-spinous point of the tibia with respect to the mid-condylar point of the femur.

Digital imaging systems provide a fast and convenient approach to data acquisition and processing, with excellent reliability and precision. These systems use software with the digital equivalents of ruler, circle, goniometer, and midline tools to define bony landmarks and make measurements. In general, digital systems provide results that are in good agreement with manual methods[18,19,23,25-28].

ALTERNATIVE APPROACHES

There are several other methods for measuring frontal plane alignment. Some are based on a single knee center-point defined apart from the bones' mechanical axes, e.g., the midpoint between the tibial spines and apex of the femoral intercondylar notch[9]. This knee center-point is then used as an origin in constructing the femoral and tibial anatomic axes[8,9,17,29,30]. The various center points identified in the literature are illustrated in Figure 3[9]. Our recommendation for use of separate center points for the femoral and tibial knee surfaces is based on anatomic study[11,12] and on the very positive feature of being able to define the extent of femoral and tibial contributions to overall alignment for a comprehensive analysis (a feature not available when using a single knee center-point). Further, by identifying each bone's moment arm, the presence of subluxation is indexed, not

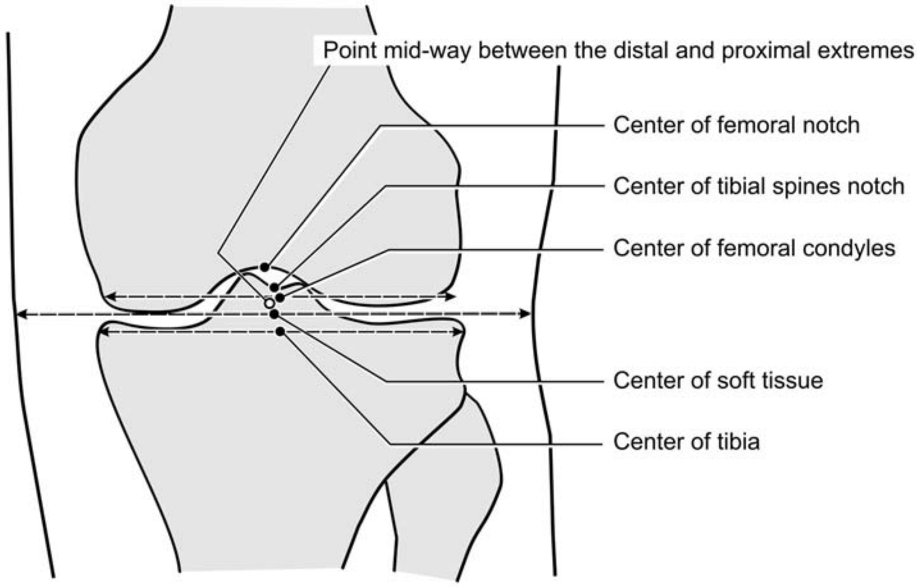

Figure 3. Centrally located points used in measures of alignment (as modified[9]). The centers of the femoral intercondylar notch and tibial spines, respectively, denote the locations of the femoral axis distally and the tibial axis proximally in our recommended approach.

hidden. Although several studies have shown the utility of anatomic measurements in defining incident knee OA and progression with alignment[29,30], the findings of such studies should be equally accessible through analysis of mechanical instead of anatomic axes.

Paley, *et al*[5,10,31] estimate lateral or medial displacement of the long bone axes by measuring linear displacement of the knee center from the LBA. This approach is a reliable and practical way to test for a malalignment. Long bone geometry is described using labels for the axes (anatomic/mechanical), the site (proximal/distal), and the side (medial/lateral)[5,10,31]. This system effectively addresses complex multifocal deformities and is widely applied in the field of limb deformity correction. The approach that we have described runs parallel to this system in many respects [for example, the mechanical lateral distal femoral angle (mLDFA) indicates the condylar surface angular orientation to the femur's mechanical axis and is exactly equivalent to the CH angle in our terminology]. Yet the angular divergence of the TM and FM axes can be measured directly via HKA, and potentially with greater accuracy and sensitivity, than by single-point lateral displacement (of relatively small amplitude) at the knee.

APPLICATIONS

During progression of knee OA, changes in HKA usually provide a sensitive indicator of deterioration due to attrition of bone and cartilage and joint space narrowing. In the clinic this is useful for monitoring the progress of individual cases in a "watch and wait" scenario, and also for followup of knee implants, where migration or loosening is usually reflected in a sharp change of HKA. Anatomic alignment measures do provide means to study relationships to OA progression, but the methods carry inherent limitations in not being able to accurately evaluate bone contributions[17,29,30]. Mechanical alignment measurements have allowed us to highlight unusual conditions, such as accelerated joint destruction evident in arthritic joints with obliquity of the articular surfaces[20,32]. In the area of research, using the same methods of measurement, we have reported variations in axial alignment between different groups with and without OA and abnormal femoral geometry (CH), specifically a reduced valgus angle at the distal femur, as a key factor in varus malalignment[16,33]. It is still unclear whether this factor is a predisposing abnormality or whether femoral changes reflect the disease in process[33].

When it comes to treatment strategy, measurement of the individual alignment values (HKA, CH, PA, CP) provides the means to understand the origin of the deformities in terms of the specific contributions of the bones and joint surfaces. On this basis the appropriate corrective measures may be applied.

A final point to be emphasized is that this comparatively simple system has been readily automated, facilitating the acquisition and networking of comprehensive alignment data for use in clinical assessments and research studies in knee disease[27,34].

SUMMARY

A systematic approach is proposed for the description and measurement of knee alignment in the frontal plane. Based on radiographs that include the hip, knee, and ankle, the method is well adapted to the clinic and for research purposes. Bony landmarks are used to locate the mechanical axes of the long bones and the orientation of the knee joint's articulating surfaces. Analysis of the geometrical relationship between the measurements reveals the underlying sources of malalignment in individual cases, which is useful for surgical planning, conservative management of knee OA, and epidemiological research. Alternative approaches using anatomic axes for measurement on short knee views have utility for specific epidemiological studies. Usually, however, the data are equally accessible by mechanical analysis, which carries the additional advantage of a more comprehensive survey of the limbs' biomechanics, providing a solid basis for comparison and the means to identify the bones' individual contributions to alignment.

These approaches are readily automated, employing digital recording and custom software with suitable electronic tools, and have proved useful in the gathering and compilation of alignment data in clinical and research applications relating to knee disease. We hope these remarks will provoke discussion and stimulate consensus for a standardized method of defining frontal plane knee alignment.

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