Radiographic Analysis of Lower Limb Axial Alignments

Adrien Durandet, Pierre-Louis Ricci, Amir Hossein Saveh, Qureish Vanat, Bin Wang, Ibrahim Esat, Mahmoud Chizari

***Abstract*— High Tibia Osteotomy (HTO) is an operation that requires full lower limb alignment assessment to plan bone cuts. This study is trying to introduce a pre HTO operative radiographic analysis method to improve measurement of the whole lower limb using anatomical and mechanical axes and the angles between them. The aim is to improve the reproducibility of the measurements, and not personalize them. Using the introduced method, the lower limb radiographic alignments of a 25 year old female patient with a varus knee deformity were analyzed pre and post operation using imaging from hip to ankle.**

***Index Terms*— High Tibial Osteotomy, Radiography, Alignment,**

I. Introduction

The High Tibial Osteotomy (HTO) is an operation which aims to re-establish the distribution of load on the articular surface within the knee by cutting (osteotomizing) the proximal (upper) part of the tibia (just distal to the tibial plateau) and opening at the position of the cut to change the lower limb geometry [1]. By performing this procedure, we will be able to observe an unloading of the diseased joint surface and therefore a loading onto the healthy surface of the joint. In performing this procedure it is important to prevent the obvious postoperative complications [2] and loss of correction [3]. In the preoperative planning for HTO surgery, lower limb anatomical and mechanical axes and the angles between the femur and the tibia have to be measured before the preceding to surgery [4]. The lower limb alignment is generally assessed two-dimensionally (2D) using gray scale radiographic images of the whole lower limb. The Hip-Knee-Ankle angle or tibio-femoral angle is important measurement to assess the varus or valgus deformity of the knee [5]. Postoperative alignment in Opening Wedge HTO depends on an accurate preoperative plan and a meticulous intraoperative technique [6].

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Adrien Durandet is with the National Engineering School of Metz (ENIM), Metz, France and the School of Design and Engineering, Brunel University West London, UK

Pierre-Louis Ricci is with the National Engineering School of Metz (ENIM), Metz, France and the School of Design and Engineering, Brunel University West London, UK

Amir Hossein Saveh is with the Shahid Beheshti University of Medical Sciences, Akhtar Orthopaedic Research Centre, Tehran, Iran

Qureish Vanat is with the Queen Elizabeth Hospital, Woolwich, UK

Bin Wang is with the School of Design and Engineering, Brunel University West London, UK

Ibrahim Esat is with the School of Design and Engineering, Brunel University West London, UK

Mahmoud Chizari is with Orthopaedic Learning and Research Center at Brunel University West London, UK, (corresponding author: Mahmoud Chizari. Phone: +447886454320; e-mail: mahmoudchizari@yahoo.com).

Although software, like mediCAD® or PreOPlan® are used to assess the lower limb alignment, there is no accurate method to define the beginning and end points of the axis and existing methods are based on assumptions that may vary from person to person. As an example, Pape and Rupp [7] define the mechanicals axis of the femur by assimilating the femoral head as a circle. The center of the circle assumes the starting reference point. The next reference point is assigned to the center of the knee, which can be found at the mid-point of a line connecting the tibial spines. In severe osteoarthritis with subluxated knee joint, two separate middle points of the tibia and femur need to be established. A perpendicular line to the subchondral joint of both proximal tibia and distal femur is drawn with the middle point being half-way from medial to lateral end of the line. The center of the tibio-talar joint is the midpoint of the talar width and the midpoint of the talar height.

To find others points Moreland et al. [2] identified five points which may be considered as the centers of the knee: the femoral notch, the tibial spines, the femoral condyles, the soft tissue and the tibia plateau. Furthermore, they identified three points for the ankle: centers of the bones, the soft tissue and the talus.

To draw the mechanicals axis, the reference points should be connected using lines. The mechanical axis of the femur is drawn by connecting the center of the knee with the center of the femoral head. The mechanical axis of the tibia is drawn by connecting the center of the knee with the center of the ankle. Another important line is the Weight-Bearing Line (WBL) which starts from the center of the femoral head and ends to the center of the ankle.

Aim of the study

The aim of this study is to introduce a new method to analyze full lower limb radiographic images and to define accurately the anatomical/mechanical axes on it. The method will also be used to examine the lower limb alignments of a subject patient with varus deformity pre and post HTO surgery for the assessment of the procedure.

II. Methods

In this study the following methods are introduced to define reference points and therefore axes of the lower limb.

We will see how to find the references point of the femur and the tibia.

A. Reference point at femoral head

To find the reference point at the femoral head a circle is sized to fit with the head. The best fit circle on the head is drawn. This can be done using three points which were located on the contour of image of the femoral head. In the example shown in Fig. 1 three points at 11, 3 and 5 o'clock on the femur head were chosen (Fig. 1a). The center of this drawn circle is then considered as the center of the femoral head and highlighted as the femoral head reference point (Fig. 1b).

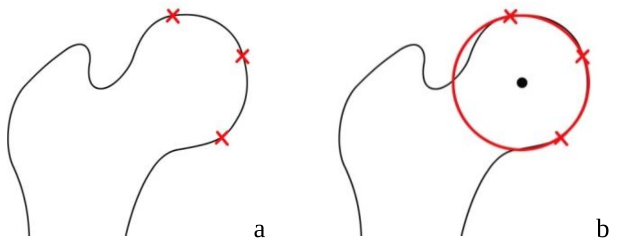

Fig. 1. Finding the center of femoral head; (a) three points located on femur head corners, (b) a circle fit with the three points

B. The femoral reference point at the knee joint

The central axis of the femur at the knee joint is found as following. Two circles are drawn on the femoral condyles by locating three points on each condyle and sizing them each with a circle (Fig. 2a). A tangent line is then drawn between on the two circles (Fig. 2b). The middle of this line between the two tangent points is defined as the reference point of the femoral bone at the knee joint.

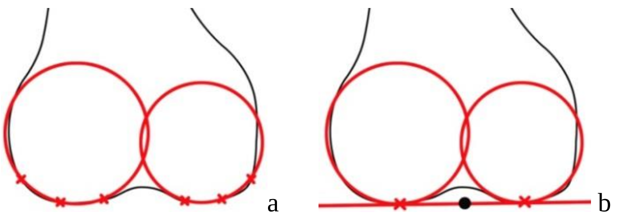

Fig. 2. Stages of finding the femur reference point at the knee joint:
1. Place 3 points on the periphery of the each condyle.
2. Fit two circles on each 3 points.
3. Draw a tangent line on these two circles.
4. Place a point in the intersection of the line and the circles.
5. The point researched is the middle of these two points.

C. The proximal tibial reference point

The central axis of the tibia at the knee joint is found in the following way. Two circles are drawn, one on the medial and one on the lateral side of the tibial plateau by fitting circles according to three points (not too close) located on the margins of the tibial plateau (Fig. 3a). Then a tangent line is drawn for the two circles (Fig. 3b). The midpoint of this line is decided with respect to the medial and lateral margins of the tibia and is considered as the reference point of the tibia at the knee. Note that the decision on where to place these two marginal points is dependent on the quality and resolution of the X-Ray image.

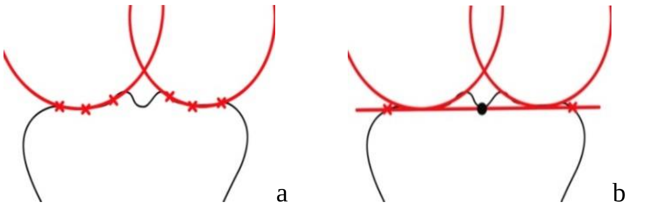

Fig. 3. Stages of finding the tibia reference point at the knee joint:
1. Place 3 points, on the joint surface of the lateral and medial parts of the tibial plateau.
2. Draw a circle on each parts of the plateau.
3. Draw the tangent of the two circles.
4. Place 2 points on the tangent line at medial/lateral margins of the tibia.
5. The middle point of this is the proximal tibial reference point.

D. Mid ankle reference point

The alignment at distal end of the tibia can be found in two stages. In the first stage, two circles should be drawn at the corners of the ankle using the three point method as introduced earlier (Fig. 4a). A line then tangent to these two circles is drawn (Fig. 4b).

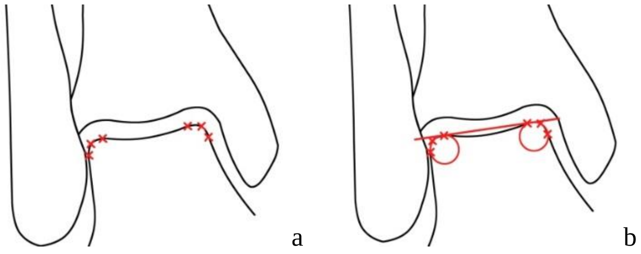

Fig. 4. Stages of finding the ankle reference point (stage1):
1. Place 3 points at the two corner of the ankle.
2. Draw two circles defined by 3 point method.
3. Draw a line tangent to these two circles.

For the second stage, another point should be placed at the tibial distal end (Fig. 5a). A line then passing through this point and parallel to the ankle tangent line should be drawn (Fig. 5b).
By performing these different steps, we are now able to draw the mechanical axes of the femur and the tibia by connecting the different references points corresponding.

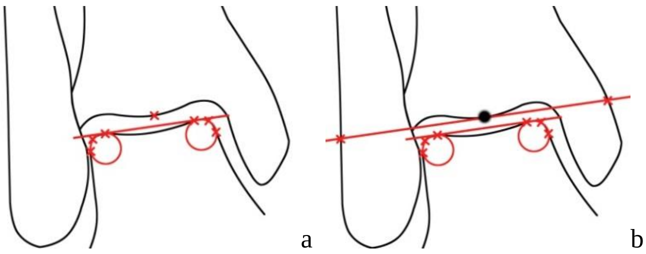

Fig. 5. Stages of finding the ankle reference point (stage2):
1. Place a point at the tibial distal end.
2. Draw a line passing through this point while the line is parallel to the ankle tangent line.
3. Place 2 points at the extremity of the tibia and the fibula.
4. The midpoint between the 2 points is the reference point at the ankle side.

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III. CASE STUDY

A. Measurement of alignment and angles in a HTO case

The Opening Wedge High Tibial Osteotomy (OWHTO) procedure was carried out on the right knee of a 25 year old female patient affected by a genu varum deformity. Full long lower limb length radiographs were obtained before and after the procedure.

Templating the radiographic image to measure alignment, the following parameters were identified:

- Hip-Knee-Ankle angle (HKA)
- Weight Bearing Line (WBL)
- WBL Angle (WBLA)
- Femoral Angle (FA)
- Tibial Angle (TA)
- Tibia Plateau Angle (TPA)
- Talar Tilt angle (TT)
- Tibia Vara angle (TV)
- Lateral Distal Femoral Angle (LDFA)
- Medial Proximal Tibia Angle (MPTA)
- Medial Distal Tibia Angle (MDTA)
- Position of the WBL regarding the tibia plateau as a percentage (WBL %)

All these parameters are normally calculated with shaft (anatomical) axes. However, their measurement introduces difficulties when the bone is bowed [8]. In this study, we will measure these parameters with mechanicals axes, using the above mentioned reference points.

B. Femoral and tibial axis and angles

To obtain the mechanical axis of the femur, a line (blue) is drawn from the femoral head reference point to the distal femoral point at the knee joint (Fig. 6).

For the mechanical axis of the tibia, a line (red) is drawn from the proximal tibial reference point calculated at the tibia plateau to the calculated reference point at the ankle (Fig. 6).

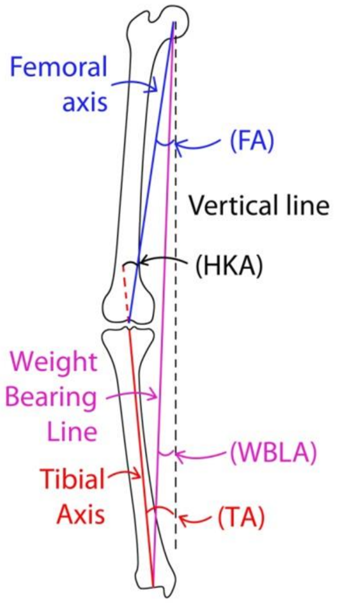

Fig. 6. Drawing the mechanicals axis of the femur and the tibia.

C. HKA angle and Weight Bearing Line

Femoral Angle (FA), which is the angle between femur mechanical axis and the vertical line and Tibial Angle (TA), which is the angle between tibial mechanical axis and the vertical line are shown in Fig. 6.

The Hip-Knee-Ankle angle (HKA) is the angle between the mechanical axis of femur and mechanical axis of tibia. As a convention the HKA angle may be expressed as its angular deviation from 180° [9].

The Weight Bearing Line (WBL) can be drawn by connecting the femoral head reference point and the ankle reference point. This line is very important and shows the direction of the body weight force. The Weight Bearing Line Angle (WBLA) is defined by the angle between the WBL and the vertical line.

D. The knee angles

Tibia Plateau Angle (TPA) is defined by the angle between proximal tibial articular line and the horizontal (Fig. 7a). The Talar Tilt angle (TT) is defined by the angle coming from the proximal talar articular line and the horizontal (Fig. 7a). The Tibia Vara angle (TV) is defined by the inclination between the distal tibial joint line and the proximal tibial joint (Fig. 7a).

The Lateral Distal Femoral Angle (LDFA) is defined by the angle between the femoral mechanical axis and the articular surface of the distal femur (Fig. 7b). The Medial Proximal Tibia Angle (MPTA) is defined by the angle between the tibial mechanical axis and the articular surface of the proximal tibia (Fig. 7b). The Medial Distal Tibia Angle (MDTA) is defined by the angle between the tibia mechanical axis and the articular surface of the distal tibia (Fig. 7b).

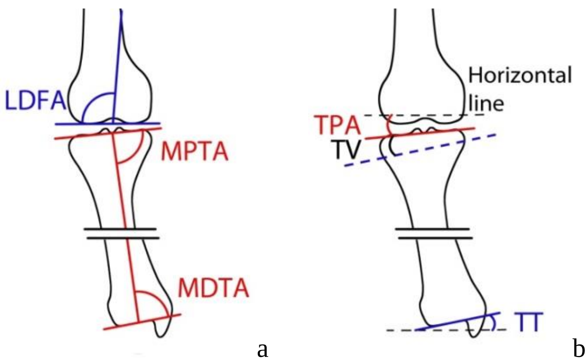

Fig. 7. Tibia Plateau Angle, Talar Tilt angle and Tibia Vara angle (a); Lateral Distal Femoral Angle, Medial Proximal Tibia Angle and Medial Distal Tibia Angle (b)

E. Position of the Weight Bearing Line

The deviation of the WBL can be quantified as a percentage of the tibia plateau width [7]. The medial edge of the medial compartment is indicated by 0% and the lateral edge of the lateral compartment by 100%. The WBL can be less than 0% or more than 100% if it passes outside the joint. Fig. 8 shows the position of the loads on the knee.

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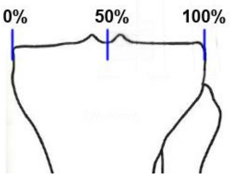

Fig. 8. Positioning of the loads on the knee

IV. RESULTS

HTO surgery aims to re-distribute the articular surface load in the knee [1]. The degree of the change in load distribution depends on the size of the osteotomy and the degree of the opening wedge created. The load on the knee can be balanced or transferred following an HTO procedure. Unloading the diseased area of the knee and reducing its contact surface and therefore the pain is the aim of HTO. Pre-operative assessment is essential to prevent the complications of over or under correction [2], [3]. An example of the method introduced in this paper is presented here. The full leg length radiograph of the patient is presented before and after the procedure in Fig. 9. Using the techniques introduced in this paper to calculate the parameters the pre and post-operative values are recorded as shown in Table I.

a b

Fig. 9. Full lower limb radiographic images of the patient before and after the operation

TABLE I
THE OUTCOME OF PRE AND POST-OPERATIVE HTO PLANNING USING THE METHOD DESCRIBED IN THIS PAPER.

	Pre-Op	**Post-Op**	**Diff.**
Hip-Knee-Ankle angle (HKA)	161.9°	178.6°	-16.7°
WBL Angle (WBLA)	-3°	0.2°	-3.2°
Femoral Angle (FA)	5.5°	1°	4.5°
Tibial Angle (TA)	-12.7°	0.4°	-13.1°
Tibia Plateau Angle (TPA)	5.5°	2.7°	2.8°
Talar Tilt angle (TT)	-22.2°	-8.6°	-13.6°
Tibia Vara angle (TV)	27.7°	11.4°	16.3°
Lateral Distal Femoral Angle (LDFA)	84.8°	84.2°	0.6°
Medial Proximal Tibia Angle (MPTA)	71.8°	86.9°	-15.1°
Medial Distal Tibia Angle (MDTA)	80.4°	81.6°	-1.2°
Position of WBL (%)	-27.3	45.5	-72.8

V. DISCUSSION

The method of measurement of lower limb geometry described in this study allows for the analysis of the preoperative condition of a 25 year old patient suffering from the effects of osteoarthric change from genu varum and thereafter, to assess her post-operative results.

The HKA angle is the most representative angle of lower limb geometry for the purpose of this study. We measured the preoperative HKA angle as 161.9° which equals a mechanical varum of 18.1°.Post operation, the HKA angle became 178.6°, which changed the mechanical varum to 1.4°. The medial condyle is still loaded but less than before the operation. The position of the WBL post confirms this. Indeed, the final force passing through the medial tibial condyle was found to be 45.5%.

The WBLA, FA and TA depend essentially on the quality of the X-ray images taken during the standing patient position. Several factors such as the knee position in the X-ray examinations caused by flexion contractures of the knee and significant varus deformities causing significant bone loss lead to errors in the measurement of the HKA [10]. To improve the reliability of templating radiographs certain criteria should be fulfilled, these include the ability to extend the knee fully, and bone loss should be taken into account to prevent errors during calculation.

The angles TPA, TT and TV allow assessment of the tibial geometry, before and after operation (as the TA). The control of tibial geometry is essential as it is the bone in which the osteotomy is performed.

The angles LDFA, MPTA and MDTA are supplementary measurements for assessment of the lower limb alignment.

VI. CONCLUSION

The aim of this study is to propose a geometric method to improve the radiographic analysis of the lower limb before perform an Opening Wedge High Tibial Osteotomy. With this method, surgeons can draw different axes and measure different angles which will give them the necessary information to make accurate predictions of the outcome postoperatively.

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