Does High Tibial Osteotomy Change the Tibia Length?

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

***Abstract*— High Tibial Osteotomy (HTO) is an accepted means of improving the symptoms of a knee deformity such as genu varum. Patient's symptoms may improve by off-loading the diseased medial compartment of the knee by changing the axis of alignment. This means that loading of the knee joint changes to the less diseased lateral compartment by an osteotomy and opening wedge thereby reducing pain, swelling, and stiffness associated with arthritis. By implication this is major surgery and requires careful preoperative assessment taking into account, patient factors, joint geometry and degree of disease in affected and less affected compartments. This study analyzes the effect of surgery on the ultimate length of the tibia compared to its preoperative state. Both Opening and Closing Wedge osteotomies were investigated in this study. The results showed that the length of tibia would increase following the Opening Wedge HTO and it would decrease by a Closing Wedge HTO. Although the change in the length of the tibia was small in comparison to its overall length the possibility of bone lengthening must be considered carefully when determining an Opening or Closing Wedge HTO, especially when a large correction angle is required.**

***Index Terms*— High Tibial Osteotomy, Genu Varum, Tibia length, Opening and Closing Wedge HTO**

I. Introduction

High Tibial Osteotomy (HTO) surgery was first described by Jackson in 1958 [1] to prevent the symptoms of osteoarthritis in the knee, and to limit its progression, thereby prolonging the function of the diseased knee. It is a method to treat unicondylar osteoarthritis at least temporarily, as satisfaction begins to fall after 5 years. Ultimately patients who are very symptomatic go on to have total knee athroplasty.

There are two methods of achieving the goal of the osteotomy: An Opening Wedge HTO (OWHTO) or a Closing Wedge HTO (CWHTO) [2] [3] [4] [5] [6] [7].

It was observed that an OWHTO tended to lengthen the tibia whereas a CWHTO had the opposite effect, to shorten it. [8] [9] [10]. In the first case, the opening of the bone cut (osteotomy site) was responsible for lengthening [9] [10] whereas shortening was seen in the second method as this required removal of a wedge of bone from the tibia and closing its ends [11] [12]. Although these observations were made, just a few studies focus on the limb lengths after HTO [13].

Currently, long length plain 2D radiographs are used to calculate the mechanical axis of the lower limb. This static image however cannot take in to account dynamic axial loading. This is why groups like Andriacchi et al. [14], claim that the static axial loading axis cannot correlate to a reproducible clinical outcome. Unfortunately inaccuracy of dynamic axis acquisition during gait is due to change in the lower limb positions such as flexion and rotation at the knee. This makes formation of a reliable focus from which to reference and template difficult, and hence calculation of axes inaccurate. [2] [15] [16].

In this study we focused on pre and post OWHTO operative parameters reflecting the length of the tibial bone with respect to a genu varum deformity. The study evaluated the postoperative limb length determined using an analytical method and compared the change in limb lengths between Opening and Closing Wedge HTO examples. Genu varum deformity means that the knee appears to be bowed outwards away from the midline. This therefore requires a medial OWHTO or a lateral CWHTO. The hypothesis was that the overall length of the tibial bone, after an OWHTO, would increase within a certain range due to the spacing introduced. While after CWHTO it becomes shorter because of the bone loss of the proximal tibia after removing a wedge. It is assumed that the change in length is negligible with a CWHTO procedure. As a result this study will concentrate on the potential limb lengthening of an OWHTO.

II. Material and Methods

A. HTO Surgery

This is a description of an Opening Wedge High Tibial Osteotomy performed on our patient. It begins with a small

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incision over the pes anserinus. This exposes the medial aspect of the proximal tibia. Retractors protect the patella, hamstring tendons, neurovascular structures and the medial collateral ligament, when approaching the bone. The next step requires drilling at the proximal tibia. This is from medial to lateral direction using fluoroscopic imaging. It should be proximal to the tibial tubercle but be 3.5cm distal to the medial joint line. The direction is towards the tip of the fibula. This drill acts a guide along which the saw passes during the osteotomy. As the saw passes medio-laterally it is important to leave the lateral edge of the tibia intact as this will act as the bony hinge as the medial part is opened using spreaders. This creates an open wedge on the medial side changing the alignment of the tibia and hence the load from the medial to lateral side. A wedge shaped block of bone graft (or bone graft substitute) is now placed into the open wedge and a locking plate is applied to hold the construct together. The last part of the operation is to ensure the correct placement of the graft and correct new alignment of the tibia with respect to the femur, this is done using fluoroscopy. Application of a hinged brace post operatively permitting only toe-touch weight bearing for several weeks (from 6 to 8 weeks) allows protected healing.

The subject patient of this study is a 25 year old female who was suffering from a genu varum deformity on her right leg. An OWHTO operation was carried out on her right knee. The procedure was performed at the Aktar Hospital by a senior Orthopaedic surgeon. The pre and post operation results of this patient were used in this study.

B. *Tibial Lengthening*

In order to assess the treatment received by the subject patient, the radiographs of her lower limb were analyzed before and after the operation. With these images it was possible to evaluate the alignment of her lower limb before and after the operation. Performing the osteotomy, not only changed the alignment of the lower limb but also the tibial bone length.

Some studies dealt with this variation due to the medial opening or the lateral closing osteotomies based on cadaveric experimentation [13]. Other authors focused on the calculation of lower limb lengths after three different osteotomies after considering the new alignment [10]. These studies did not define ways to predict outcome length, or consider the technical operative methods or have statistical data.

Plateau-Ankle angles were determined pre and post operatively because HTO modifies these values directly. In varus knees the tibial axis is angled medially with respect to the tibial plateau, named AB [15]. It is therefore directly linked to tibial geometry and are useful pre and post operative parameters.

C. *Tibia's Lengthening with Opening Wedge HTO*

The Fig. 1 illustrates the modification of the tibia's geometry due to HTO with A and B points representing respectively the beginning and the end of the tibia's mechanical axis. It is clear to see the mechanical axis of the tibia lengthens as the initial distance AB becomes AB' because B is shifting to B' position.

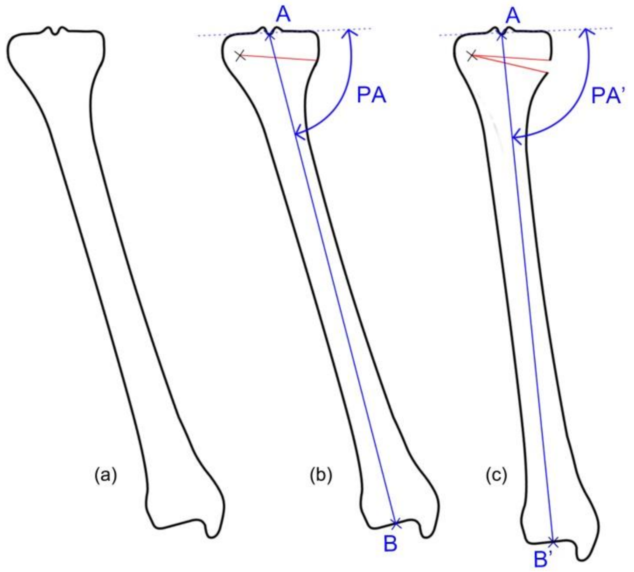

Fig. 1. OWHTO performed on the tibia; original bone (a); OWHTO cut (b); OWHTO (c). The Plateau-Ankle (PA) angle pre and post-operatively is also shown on the picture.

It is possible to calculate the lengthening that the tibia will be subjected to by knowing the PA angle. New tibial length is dependent on the position of the hinge (the lateral end of bone not cut by the saw) as the opening wedge rotates about this point (marked 'O' Fig. 2). It is therefore necessary to define a landmark according to its position in the plane assimilated to the radiograph as illustrated in the following Fig. 2.

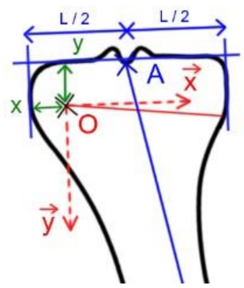

Fig. 2. Schematic of the tibial bone and the used landmark in this study (OWHTO case)

We can assume at this point the tibia is divided in two different parts; that above the osteotomy (static) and that below the osteotomy (dynamic). It is the dynamic segment that moves laterally creating the opening wedge around the lateral hinge. This hinge as mentioned above is located at the farthest point of the osteotomy (position 'O' Fig. 2) and acts as the centre of rotation. Therefore, we can say the distance separating this precise point O and the end of the mechanical axis of the tibia B or B' is not changing after the operation. Using a coordinate system, the initial length of TM ([AB]), the plateau's width (L), PA values and parameters of the surgical procedure (X and Y), we can add the definition of [OB] (1) and [OB'] (2) in this plane and deduce a 2[nd] degree equation (6) reflecting the new value of TM (7) ([AB']):

$$[OB] = \sqrt{[AB]^2 + [AB]\left((L-2x)\cos PA - 2y \times \sin PA\right) + \left(\frac{L}{2} - x\right)^2 + y^2} \qquad (1)$$

[OB] is joining O and B, respectively the endpoint of the cut and the center of the ankle before the operation.

$$[OB'] = \sqrt{[AB']^2 + [AB']\big((L-2x)\cos PA' - 2y \times \sin PA'\big) + \left(\frac{L}{2} - x\right)^2 + y^2} \quad (2)$$

[OB'] is the distance between O and B', respectively the endpoint of the cut and the center of the ankle after the operation.

[OB] and [OB'] should have the same length as O is considered as the center of the rotation and these two distances represent the radius of this circle. We can therefore deduce the following equations:

$$[OB'] = [OB] \quad (3)$$

By replacing the respective values of [OB] and [OB'] found in equation (1) and (2), we can reach these results and express a 2nd degree equation (6) reflecting the new value of TM (7) ([AB']):

$$(3) \leftrightarrow [OB']^2 = [OB]^2 \quad (4)$$

$$(4) \leftrightarrow [OB']^2 - [OB]^2 = 0 \quad (5)$$

$$(5) \leftrightarrow [AB']^2 + b \times [AB] + c = 0 \quad (6)$$

$$b = (L - 2x)\cos PA' - 2y \sin PA'$$

$$c = -[AB]^2 - [AB][\,(L - 2x)\cos PA - 2y \sin PA\,]$$

Values of b and c unknowns are expressed previously and lead to the new value of the tibia's length [AB'] (7):

$$(6) \leftrightarrow [AB'] = \frac{-b + \sqrt{b^2 - 4 \times c}}{2} \quad (7)$$

D. *Tibia's Shortening with Closing Wedge HTO*

The previous Fig. 3 shows the changes affecting the tibia after CWHTO. Unlike the previous surgical procedure, this requires a wedge of bone being removed. The gap created is closed and fixed again with a plate and screws. Points A and B represent the tibia's mechanical axis. In this case, we observe a shortening of the mechanical axis of the tibia as length AB becomes AB' after the intervention.

Once again, using the same parameters CW changes were similarly evaluated this time for relative shortening of the tibia. PA angles proved to be useful with respect to the hinge defined again as point 'O' but modified as the osteotomy was performed from the lateral side, as we can see in Fig. 4.

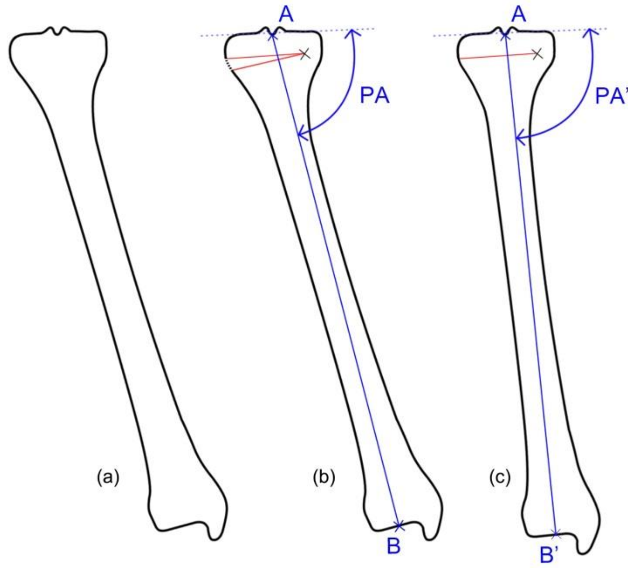

Fig. 3. CWHTO performed on the tibia; original bone (a); CWHTO cuts (b); CWHTO (c). The Plateau-Ankle (PA) angle pre and post-operatively is shown on the picture.

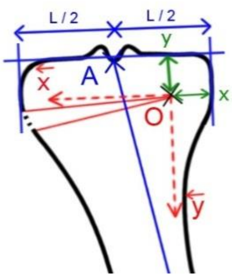

Fig. 4. Schematic of the tibial bone and the used landmark in this study (CWHTO case)

One more time we can assume the hypothesis introduced in the previous paragraph which considers O as a hinge for the rotation. This assumption lead to the same observations: values [OB] (distance joining the end of the cut O and the bottom extremity of the mechanical axis before the operation) and [OB'] (same distance but considered after the operation) stay equals to each other. Such as before, using the Appropriate coordinate system, the initial length of TM ([AB]), the plateau's width (L), PA values and parameters of the surgical procedure (X and Y), we can reach the definition of [OB] (8) and [OB'] (9) in order to find the 2nd degree equation EEE displaying the value of TM after the operation EEE (AB'):

$$[OB] = \sqrt{[AB]^2 + [AB]\big((2x-L)\cos PA - 2y \times \sin PA\big) + \left(\frac{L}{2} - x\right)^2 + y^2} \quad (8)$$

[OB] is the value of the line linking the end of the two cuts O and the bottom extremity of the mechanical axis before the operation.

$$[OB'] = \sqrt{[AB']^2 + [AB']\big((2x-L)\cos PA' - 2y \times \sin PA'\big) + \left(\frac{L}{2} - x\right)^2 + y^2} \quad (9)$$

[OB'] is similar to the definition here before but it considers the case after the operation, this means O and B' points.

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Once again, because O is judged as the center of the hinge, the distance joining O and the end of tibia's mechanical axis before and after the operation is unchanged:

$$[OB'] = [OB] \tag{10}$$

Same reasoning as before in applied in this case: replacing values of [OB] (8) and [OB'] (9) guides to the researched 2nd degree equation (13) introducing the new value of TM (14) ([AB']).

$$(10) \leftrightarrow [OB']^2 = [OB]^2 \tag{11}$$

$$(11) \leftrightarrow [OB']^2 - [OB]^2 = 0 \tag{12}$$

$$(12) \leftrightarrow [AB']^2 + b \times [AB] + c = 0 \tag{13}$$

$$b = (2x - L)\cos PA' - 2y \sin PA'$$

$$c = -[AB]^2 - [AB][\,(2x - L)\cos PA - 2y \sin PA\,]$$

Values of b and c unknowns are expressed previously and lead to the new value of the tibia's length [AB'] (14):

$$(13) \leftrightarrow [AB'] = \frac{-b + \sqrt{b^2 - 4 \times c}}{2} \tag{14}$$

III. Result and discussion

This study evaluated the relative lengths of the tibia pre and post OW and CW HTO surgery. The preoperative genu varum knee showed a PA angle of 72.3° and reflected a deformity close to 18.1° with respect to the mechanical axis of the femur to the tibia. In order to restore a better alignment of the tibia relative to the femur HTO surgery improved the PA angle to 86.3° leading to an HKA angle of 178°. Calculations for both the OWHTO and CWHTO cases were performed. Evaluations were made for the relative changes in mechanical axes and their resultant lengths.

For the OWHTO case, preoperative tibial length was 337.5 mm but after the intervention it reached 344.4 mm. Opening wedge osteotomy increased the tibia by almost 7 mm by changing the initial 18.1° mechanical varus deformity to a HKA angle of 178°. Clinically this degree of opening was required to achieve the aim of the operation, that being to off-load the diseased medial compartment onto the disease free lateral compartment by changing the mechanical axis. We also found that there was not just a link between the tibial length and PA angle but there was a proportional relationship between them. Table I reports the measures obtained from the patient's tibia pre and post operation and also shows the difference from the operation.

The result of the tibial length in Table II assumes that the patient obtained a closing wedge HTO.

TABLE I
TIBIAL LENGTH PRE AND POST OPENING WEDGE HTO

Measurements	Pre Op	Post Op
PA (°)	72.3	86.3
Cutting Angle (°)	0	14
Tibia length (mm)	337.5	344.4

TABLE II
TIBIAL LENGTH PRE AND POST CLOSED WAGE HTO

Measurements	Pre Op	Post Op
PA (°)	72.3	86.3
Cutting Angle (°)	0	14
Tibia length (mm)	337.5	337

IV. Conclusion

In conclusion, there was a change in tibia length after opening and closed-wedge HTO. The change for OWHTO was considerable while the tibial length change in CWHTO was negligible. The tibia length increased 6.9 mm after the opening wedge HTO and was reduced by 0.5 mm following closed wedge HTO surgery. The osteotomy correction angle was 14 degrees for both cases. The greater the correction in axis the greater the change in the tibia length.

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