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Original Article

A novel technique in open wedge high tibial osteotomy to preserve the tibial slope: a basic study on cadaver and reconstruction CT scanning

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Abstract: High tibial osteotomy (HTO) is a well-established treatment option for uni-compartmental osteoarthritis. Recently, medial opening wedge HTO has become the primary surgical technique. It is very important in a high tibial open wedge osteotomy to keep the slope unchanged in the sagittal plane. The purpose of this study is to introduce a quantitative method of open wedge HTO to preserve the tibial slope without considering the osteotomy line. At first, mathematical calculations were concentrated, and the relations, formulas and tables were extracted. The results of formulas and tables were examined using software on reconstruction CT scanning of two intact tibiae (Level of Evidence: V). Then the results of the calculations were tested on five real cadavers. Software results showed that the changes in slope angle using the simplified formulas and tables are less than 0.5° in both subjects. Based on the *p*-value, the simplified formula or the tables can be used to correct the varus with minimal change in the slope and without considering osteotomy line. Results from osteotomies on 5 bones showed that changes in slope angle were significantly small. In 3 subjects, the change was less than 0.6°. Use of this new technique in open wedge HTO can result in good varus correction with minimal changes to the tibial slope, regardless of the orientation of the osteotomy line.

Keywords: High tibial osteotomy, open wedge, tibial slope, surgical technique, formula

Introduction

High tibial osteotomy (HTO) is a well-established treatment option for uni-compartmental osteoarthritis associated with coronal deformity of the lower limb [1]. Clinical indications for an HTO include varus alignment of the knee associated with medial compartment arthritis, knee instability, medial compartment overload following meniscectomy, and osteochondral lesions requiring resurfacing procedures [1].

Many techniques have been described for HTO. The goal of the procedure is to realign the lower extremity and redistribute the joint forces applied to each compartment of the knee, thereby decreasing pain and improving overall function [1, 2]. The technique used for proximal tibia osteotomy has typically been the lateral closing wedge. In recent years, the medial opening wedge technique has gained popularity. The primary focus of both is to alter the weight-bearing axis in the coronal plane. Both methods have been shown to produce satisfactory clinical results in both the short- and long-term [1-4]. Lateral closing wedge HTO was once considered to be the standard of care; however, this technique is associated with fibular osteotomy or proximal tibiofibular joint disruption, peroneal nerve injury, more demanding subsequent total knee arthroplasty (TKA), and loss of bone stock [1]. Recently, medial opening wedge HTO has become the primary surgical technique [2]. Disadvantages associated with medial opening wedge HTO include the need for bone grafting and the risk of collapse or loss of correction [5].

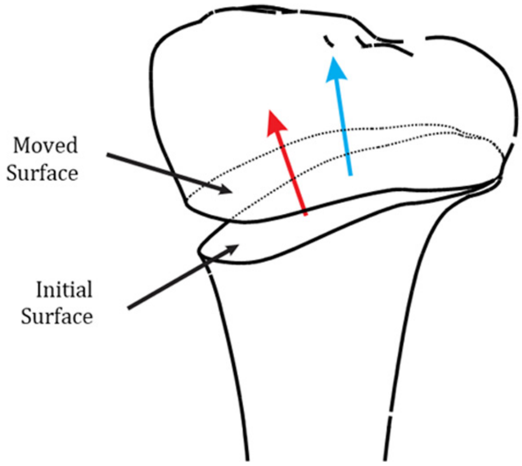

Figure 1. The moved and initial surfaces with corresponding normal vectors (red vector corresponding to the initial surface and blue vector corresponding to the moved surface).

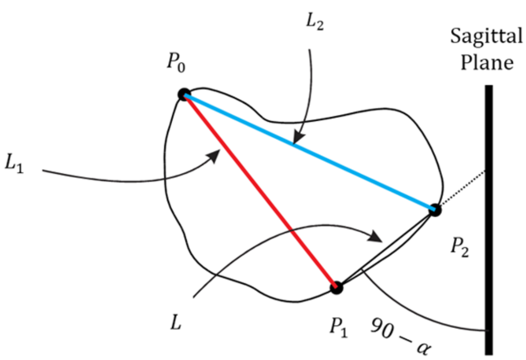

Figure 2. Presentation of defined points, lengths and angles on tibial cut plane. Sagittal Plane is the Sagittal Plane of whole body.

It is very important in a high tibial open wedge osteotomy to keep the slope unchanged in the sagittal plane; it should mimic the proximal tibial joint slope [6].

The proximal anteromedial cortex, when viewed in cross section, has an oblique or triangular shape, whereas the lateral tibial cortex is nearly perpendicular to the posterior margin of the tibia. Thus, in an open wedge high tibial osteotomy, if the wedge gap has an equal anterior and posterior diameter, the tibial slope will be increased [5].

Noyes et al. [7] showed that in order for the tibial slope to remain unchanged, the osteotomy line must be parallel to the tibial slope, and the most anterior gap of the osteotomy wedge at the tibial tubercle should be one-half the posteromedial gap. Every millimeter of gap error at the tibial tubercles results in approximately 2° of change in the tibial slope [7]. In some conditions, however, during the open wedge HTO, the osteotomy line may not be parallel to the tibial plateau. In such cases, it is necessary to find a method to keep the slope unchanged.

This study aimed to introduce a quantitative method of open wedge HTO to preserve the tibial slope without considering the osteotomy line. To the best of our knowledge, this is the first study to introduce a method for open wedge HTO that keeps the tibial slope unchanged despite the osteotomy line.

Materials and methods

At first, calculations were concentrated, and then relations and tables were extracted from that data. In the next step, results from the previous part were tested in the 3D software. In the last step, the results of the calculation were tested on real cadavers, and the results were compared.

Calculations

The first assumption is that the cut surface is a plane (smooth cut). Therefore, a plane equation can be written for the cut surface. Obviously, at least 3 points of the plane (non-aligned) were needed to make a unique plane. For convenience, we should be chosen so obtain coordinates of the 3 non-aligned points was a simple task. In this study, the three points were defined as follows:

- Point Zero: This point is the end of the cut, and when opening the osteotomy site, the bone fragments are driven around it. The coordinates of this point are (0,0,0).

- Point One: This point is on the cortical bone of the tibia; the surgeon can see it during surgery. An effort is made to select this point at the posterior medial cortex that is available to the surgeon. The coordinates of this point are (x_1, y_1, z_1).

- Point Two: This point is similar to "Point One" on the same cortical tibia bone, the only differ-

Table 1. Subject parameters in the software in both parallel and non-parallel cut

Subject	Cutting Angle [Deg]	L_1 [mm]	L_2 [mm]	Correction Varus Angle [Deg]
#1 (parallel)	46	57.4	63.5	10
#1 (5° increase)	48	57.94	63.74	10
#2 (parallel)	46.41	59.7	61.34	10
#2 (10° increase)	46.41	47.74	51.22	10

Table 2. *p*-values for **Figure 7**'s data, included 0 to 20 degree

Subject	Calculate From Table	
	Parallel	Nonparallel
#1	1.51e-8	1.74e-6
#2	2.03e-8	1.06e-7

ence being it is placed more on the frontal medial cortex. The coordinates of this point are (x_2, y_2, z_2) (**Figure 2**).

The two planes were defined as follows:

● Initial surface: Cropped area is located on the posterior piece of the tibia. It is assumed that the surface is fixed and does not move during surgery.

● Moved surface: After the cut, this surface is separated from the initial surface and displaced by rotating the inferior tibia fragment around Point Zero (**Figure 1**).

Calculating the coordinates of points

Detecting the coordinates of two points on a complex surface like a tibia during surgery is a difficult task. Therefore, a simple method is proposed in this study that can obtain x_1, x_2, y_1 and y_2 coordinates.

Instead of calculating these four parameters, four new parameters are defined, the measurement of which is simpler for the surgeon than x_1, x_2, y_1 and y_2 coordinates. If the sizes of three sides of the triangle are known, a unique triangle can be produced on plan. To define the triangle direction, we can measure the angle between triangle height and sagittal plan (x axis). So:

● L_1 is the distance between points 1 and 0.

● L_2 is the distance between points 2 and 0.

● L is the distance between points 2 and 1.

● α is the angle between triangle height and sagittal plan. If $\sphericalangle\overline{P_1P_2}$ is the angle between x plan and line from 1 to 2 point: $\alpha = 90 - \sphericalangle\overline{P_1P_2}$ (**Figure 2**).

Height (z) on all three points is supposed to equal zero.

If H is the height of the triangle, and S_1 and S_2 are the distance of the point of impact of height with the rule of triangles to points 1 and 2, respectively, we have from the trigonometric relationships:

$$x_1 = H\cos\alpha + S_1\sin\alpha \quad \text{Eq. 1(a)}$$

$$y_1 = H\sin\alpha - S_2\cos\alpha \quad \text{Eq. 1(b)}$$

$$x_2 = H\cos\alpha - S_2\sin\alpha \quad \text{Eq. 1(c)}$$

$$y_2 = H\sin\alpha + S_2\cos\alpha \quad \text{Eq. 1(d)}$$

Eq. 1 can also be proved:

$$S = S_1 = \frac{L_1^2 - L_2^2 + L^2}{2L} \quad \text{Eq. 2(a)}$$

$$S_2 = \frac{-L_1^2 + L_2^2 + L^2}{2L} \quad \text{Eq. 2(b)}$$

$$H = \frac{1}{2L}\sqrt{4L_1^2L_2^2 - \left(L^2 - L_1^2 - L_2^2\right)^2} \quad \text{Eq. 2(c)}$$

To obtain an accurate value of the opening of the mathematical techniques, solving the nonlinear system of 7 equations and 7 unknown variables is required. Due to the numerical solution, which is very complex, solving these 7 equations is almost impossible for the surgeon. To simplify the equations, several assumptions need to be applied, and the particular circumstances must be evaluated. It is assumed that coordinates *x* and *y* are any two points in two identical value and are different only in the value of z; it can be deduced from this assumption that the created triangle on the moved plan is the image of the triangle on the initial plan in the direction of z on the moved plan, and it is not rotated. Although the nature of the movement here has changed, because the angles are small, a good approximation can be made.

The slope angle cannot be changed. In this case the amount of sides opening can be extracted from this simple formula:

$$\begin{cases} W_1 = A.H - B.S \\ W_2 = W_1 + L.B \end{cases} \quad \text{Eq. 3}$$

Where W_1 and W_2 are the openings of the wedges in points 1 and 2, respectively. H and S can be obtained from Eq. 2. Note that S was consid-

Table 3. Results from osteotomy on the tibia with new way and without considering osteotomy orientation

Subject			Cutting Angle [Deg]	Chang of Slop Angle [Deg]	Varus Angle Correction [Deg]
#1	60	65	45	0.55	7.76
#2	-	-	-	-	-
#3	65	70	45	0.39	10.05
#4	59	67	45	0.41	9.37
#5	63	66	45	1.87	7.09
	Mean			0.8	8.57

ered equal to S_1. In **Figure 2**, L is the distance between points 1 and 2 and was considered equal to 25 mm in all surgeries. A and B could be determined from the following equation:

$$A = \sin\alpha\tan\theta_c \quad \text{Eq. 4(a)}$$

$$B = \cos\alpha\tan\theta_c \quad \text{Eq. 4(b)}$$

Where θc is the corrected angle of varus, which the surgeon is going to apply?

Because of the complex relationship between H and S, for the convenience of the surgeon, **Table 4** presents values of H and S in terms of L_1 and L_2 and for L = 25 mm. Note that the smaller parameter (usually L_1) will be on the horizontal axis and the larger parameter (usually L_2) on the vertical axis. For these two parameters, two values will be obtained, the first of which will be H and the second S.

Obtaining the two parameters A and B is also difficult for the surgeon. For simplicity, **Table 5** is presented that α is the horizontal axis and θc is the vertical axis. As expected, obtaining the parameter α in the tibia is difficult for the surgeon. Because the value of this angle is 45°±6° (Noyes, Goebel, & West, 2005), the value of α can be 45°.

It is recommended that when using the table, parameters measured (L_1 and L_2) be rounded down.

Software testing

At this point, two intact tibia (First subject: female, 45 years old, 161 cm tall; second subject: male, 38 years old, 177 cm tall) were used. Using CT images and image processing, a three-dimensional model was created. Images were taken by bi-directional scanner (model: SIEMON/EMOTION, resolution: 512 × 512 pixels) with a 1.199 mm slice increment.

After photographing the bones, a three-dimensional model was created by image processing and was cut into two modes in the software. The first cut was parallel to the slope, and for the second, a non-parallel cut was performed. Then, by using the obtained formulas, a gap was created and regulated for both bones to the corrected angle of 10°, and the angles were measured. This section shows the formula in an ideal case.

Cadaveric study

Five fresh proximal tibia cadavers were prepared. The anteroposterior and true lateral X-ray were tacked, and the tibia slopes were determined in all models. In the working room, Point Twos were first determined in the anteromedial tibial cortex to be 25 mm apart (**Figure 3A** and **3B**).

Two wires were then inserted at determined points from medial to lateral side; they reached each other at Point One on the lateral side (**Figure 4A** and **4B**). This procedure was done under fluoroscopic control using an ACL guide device.

Using the identically-sized pins, the length of the anterior (L_1) and posterior (L_2) distances from determined points to the lateral cortex were measured.

Then the proximal tibial cut was made proximal to the tibial tuberosity without considering the tibial slope. It was planned to correct all specimens 10°. Using the table, the anterior and posterior gaps were opened with a scaled spreader, the osteotomy site was fixed with a T buttress plate, and AP and true lateral x-says were taken. The tibial slope and amount of correction were measured on the x-rays (**Figure 5**).

Results

Software results of osteotomy tibia

Each bone was tested twice: one with a slope cut parallel, and one with a slope cut non-parallel to the tibial slope. The osteotomy was done proximal to the tibial tuberosity. Two charts for each cut were presented that showed actual modified varus angle and changes in slope angle versus different (expected) varus angles.

The measured parameters calculated by computer for the two subjects are shown in **Table 1**.

Table 4. Values of H and S corresponding to the L_1 and L_2

		L_1 (mm)																				
		55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
L_2 (mm)	55	53.56																				
		12.50																				
	56	54.03	54.59																			
		10.28	12.50																			
	57	54.41	55.06	55.61																		
		8.02	10.24	12.50																		
	58	54.70	55.43	56.08	56.64																	
		5.72	7.94	10.20	12.50																	
	59	54.90	55.72	56.46	57.10	57.66																
		3.38	5.60	7.86	10.16	12.50																
	60	54.99	55.91	56.74	57.48	58.13	58.68															
		1.00	3.22	5.48	7.78	10.12	12.50															
	61	54.98	55.99	56.92	57.75	58.50	59.15	59.71														
		-1.42	0.80	3.06	5.36	7.70	10.08	12.50														
	62	54.86	55.98	57.00	57.93	58.77	59.51	60.17	60.73													
		-3.88	-1.66	0.60	2.90	5.24	7.62	10.04	12.50													
	63	54.63	55.85	56.97	58.00	58.94	59.78	60.53	61.19	61.75												
		-6.38	-4.16	-1.90	0.40	2.74	5.12	7.54	10.00	12.50												
	64	54.27	55.60	56.83	57.96	59.00	59.94	60.79	61.55	62.21	62.77											
		-8.92	-6.70	-4.44	-2.14	0.20	2.58	5.00	7.46	9.96	12.50											
	65	53.78	55.23	56.57	57.81	58.95	60.00	60.95	61.81	62.57	63.23	63.79										
		-11.50	-9.28	-7.02	-4.72	-2.38	0.00	2.42	4.88	7.38	9.92	12.50										
	66	53.16	54.72	56.18	57.53	58.79	59.94	61.00	61.96	62.82	63.58	64.24	64.81									
		-14.12	-11.90	-9.64	-7.34	-5.00	-2.62	-0.20	2.26	4.76	7.30	9.88	12.50									
	67	52.38	54.07	55.66	57.13	58.50	59.77	60.93	62.00	62.96	63.83	64.60	65.26	65.82								
		-16.78	-14.56	-12.30	-10.00	-7.66	-5.28	-2.86	-0.40	2.10	4.64	7.22	9.84	12.50								
	68	51.43	53.27	54.99	56.59	58.08	59.47	60.75	61.92	63.00	63.97	64.84	65.61	66.28	66.84							
		-19.48	-17.26	-15.00	-12.70	-10.36	-7.98	-5.56	-3.10	-0.60	1.94	4.52	7.14	9.80	12.50							
	69	50.31	52.31	54.17	55.91	57.53	59.03	60.43	61.72	62.91	63.99	64.98	65.85	66.63	67.30	67.86						
		-22.22	-20.00	-17.74	-15.44	-13.10	-10.72	-8.30	-5.84	-3.34	-0.80	1.78	4.40	7.06	9.76	12.50						
	70	48.99	51.16	53.18	55.06	56.82	58.46	59.99	61.40	62.70	63.90	64.99	65.98	66.86	67.64	68.31	68.87					
		-25.00	-22.78	-20.52	-18.22	-15.88	-13.50	-11.08	-8.62	-6.12	-3.58	-1.00	1.62	4.28	6.98	9.72	12.50					
	71	47.45	49.81	52.00	54.05	55.96	57.74	59.40	60.94	62.36	63.68	64.89	65.99	66.98	67.87	68.65	69.33	69.89				
		-27.82	-25.60	-23.34	-21.04	-18.70	-16.32	-13.90	-11.44	-8.94	-6.40	-3.82	-1.20	1.46	4.16	6.90	9.68	12.50				
	72	45.65	48.23	50.62	52.85	54.92	56.85	58.65	60.33	61.89	63.33	64.66	65.88	66.99	67.99	68.88	69.67	70.34	70.91			
		-30.68	-28.46	-26.20	-23.90	-21.56	-19.18	-16.76	-14.30	-11.80	-9.26	-6.68	-4.06	-1.40	1.30	4.04	6.82	9.64	12.50			
	73	43.56	46.40	49.01	51.44	53.69	55.79	57.74	59.57	61.26	62.83	64.29	65.63	66.86	67.98	68.99	69.89	70.68	71.36	71.92		
		-33.58	-31.36	-29.10	-26.80	-24.46	-22.08	-19.66	-17.20	-14.70	-12.16	-9.58	-6.96	-4.30	-1.60	1.14	3.92	6.74	9.60	12.50		
	74	41.13	44.27	47.14	49.79	52.25	54.53	56.66	58.64	60.48	62.19	63.78	65.25	66.61	67.85	68.98	69.99	70.90	71.69	72.37	72.94	
		-36.52	-34.30	-32.04	-29.74	-27.40	-25.02	-22.60	-20.14	-17.64	-15.10	-12.52	-9.90	-7.24	-4.54	-1.80	0.98	3.80	6.66	9.56	12.50	
	75	38.27	41.79	44.97	47.89	50.58	53.07	55.38	57.53	59.53	61.39	63.12	64.73	66.22	67.58	68.83	69.97	71.00	71.91	72.70	73.39	73.95
		-39.50	-37.28	-35.02	-32.72	-30.38	-28.00	-25.58	-23.12	-20.62	-18.08	-15.50	-12.88	-10.22	-7.52	-4.78	-2.00	0.82	3.68	6.58	9.52	12.50

Table 5. Values of A and B corresponding to the and Correction angle (θ)

		Correction angle (α) [deg]																				
		35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55
Correction angle (α) [deg]	1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
		0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	3	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	4	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06
		0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04
	5	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
		0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05
	6	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09
		0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06
	7	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10
		0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07
	8	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.12
		0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.08
	9	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13
		0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.09	0.09
	10	0.10	0.10	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.14	0.14
		0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.10	0.10
	11	0.11	0.11	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.16
		0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.11	0.11
	12	0.12	0.12	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.17	0.17	0.17	0.17	0.17
		0.17	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.15	0.15	0.15	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.12	0.12
	13	0.13	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.19	0.19
		0.19	0.19	0.18	0.18	0.18	0.18	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.14	0.14	0.14	0.13
	14	0.14	0.15	0.15	0.15	0.16	0.16	0.16	0.17	0.17	0.17	0.18	0.18	0.18	0.19	0.19	0.19	0.19	0.20	0.20	0.20	0.20
		0.20	0.20	0.20	0.20	0.19	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17	0.17	0.16	0.16	0.16	0.15	0.15	0.15	0.14
	15	0.15	0.16	0.16	0.16	0.17	0.17	0.18	0.18	0.18	0.19	0.19	0.19	0.20	0.20	0.20	0.21	0.21	0.21	0.21	0.22	0.22
		0.22	0.22	0.21	0.21	0.21	0.21	0.20	0.20	0.20	0.19	0.19	0.19	0.18	0.18	0.18	0.17	0.17	0.16	0.16	0.16	0.15
	16	0.16	0.17	0.17	0.18	0.18	0.18	0.19	0.19	0.20	0.20	0.20	0.21	0.21	0.21	0.22	0.22	0.22	0.23	0.23	0.23	0.23
		0.23	0.23	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.21	0.20	0.20	0.20	0.19	0.19	0.18	0.18	0.18	0.17	0.17	0.16
	17	0.18	0.18	0.18	0.19	0.19	0.20	0.20	0.20	0.21	0.21	0.22	0.22	0.22	0.23	0.23	0.23	0.24	0.24	0.24	0.25	0.25
		0.25	0.25	0.24	0.24	0.24	0.23	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.20	0.20	0.20	0.19	0.19	0.18	0.18	0.18
	18	0.19	0.19	0.20	0.20	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.23	0.24	0.24	0.25	0.25	0.25	0.26	0.26	0.26	0.27
		0.27	0.26	0.26	0.26	0.25	0.25	0.25	0.24	0.24	0.23	0.23	0.23	0.22	0.22	0.21	0.21	0.20	0.20	0.20	0.19	0.19
	19	0.20	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.26	0.27	0.27	0.27	0.28	0.28
		0.28	0.28	0.27	0.27	0.27	0.26	0.26	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.23	0.22	0.22	0.21	0.21	0.20	0.20
	20	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.27	0.28	0.28	0.29	0.29	0.29	0.30
		0.30	0.29	0.29	0.29	0.28	0.28	0.27	0.27	0.27	0.26	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.22	0.22	0.21	0.21

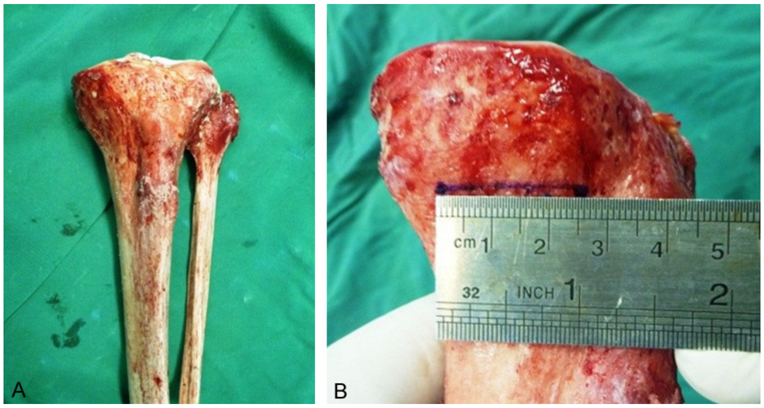

Figure 3. A and B: Determining two points (2.5 cm apart) on anteromedial cortex.

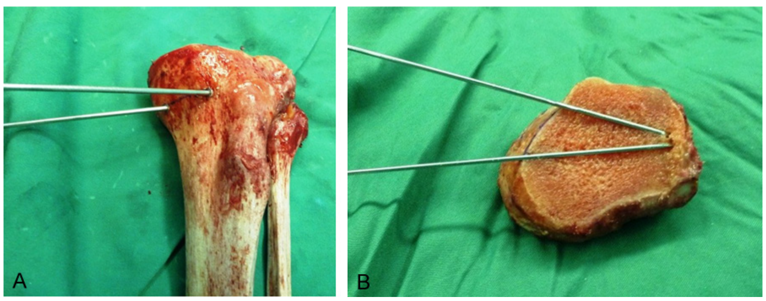

Figure 4. (A and B) Inserting two pins from determined points (A) to cross on lateral cortex (B).

In **Figure 6**, the varus angles calculated by different methods depending on the modified varus angle (expected) were plotted from zero to 20°. The gray curve showed the exact solution of the nonlinear numerical solution of the 7 equations system, and the 7 unknowns were obtained. The black curve was solved using a simple formula by which the error was less than 0.2°. The blue and red point-line curves showed the performance when using tables for non-parallel (slope increase of 5° for the first subject and 10° for the second) and parallel cutting. As shown, the error was less than 0.5° when using the table.

In comparing curves A with B in **Figure 6**, no significant difference was seen between the figures. This result showed the efficiency of this method in response to different conditions. In order to achieve modified varus angle correction, **Tables 4** and **5** or the formulas could be used.

In **Figure 7**, the changes in slope angle using the simplified formulas and tables were presented. It was clear that the results of seven simultaneous exact equations were always zero. In the curve that was related to the simplified formula, (black continuous curve), an increase in the slope angle in respect to the increase in the angle of the varus correction was seen. This increase was less than 0.5° in both subjects. In the curve related to use of the tables, slope angles increased in all cases but one, and all were less than 1.

In **Table 3**, a comparison of changes in slope using the two mentioned ways were presented. Based on the *p*-value, the simplified formula or the tables could be used to correct the varus, or least change in the slope without osteotomy angle.

From the low *p*-value it could be concluded that assuming a value of less than 1 is not a fail, and we could calculate that the median of the data was less than 1 in this domain **Table 2**.

Results from osteotomies on 5 bones were presented in **Table 3**. In this experiment, subject 2's bone was broken in the procedure and was therefore eliminated. To compress the data, the value of the varus correction for all subjects was assumed to be 10°. As seen in **Table 3**, the changes in the angle of the slopes were significantly small. In 3 subjects, the change was less than 0.6°. Especially in subjects 3 and 4, the correction of the varus was significantly close to 10° (the desired value) **Figure 8**.

Discussion

The successful correction of misalignment by a medial opening wedge osteotomy has been reported [8-11]. A number of technical improvements have contributed to the safety and reproducibility of this technique [12]. Advantages of this technique include the requirement for only a single osteotomy with surgical dissection away from the peroneal nerve, no violation of the fibula and tibiofibular joint, and the capabil-

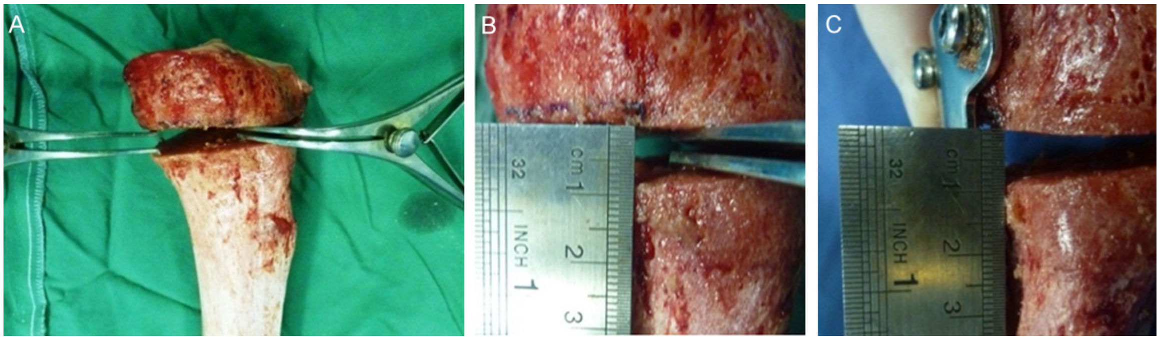

Figure 5. A-C: Opening anterior and posterior gaps and fixation.

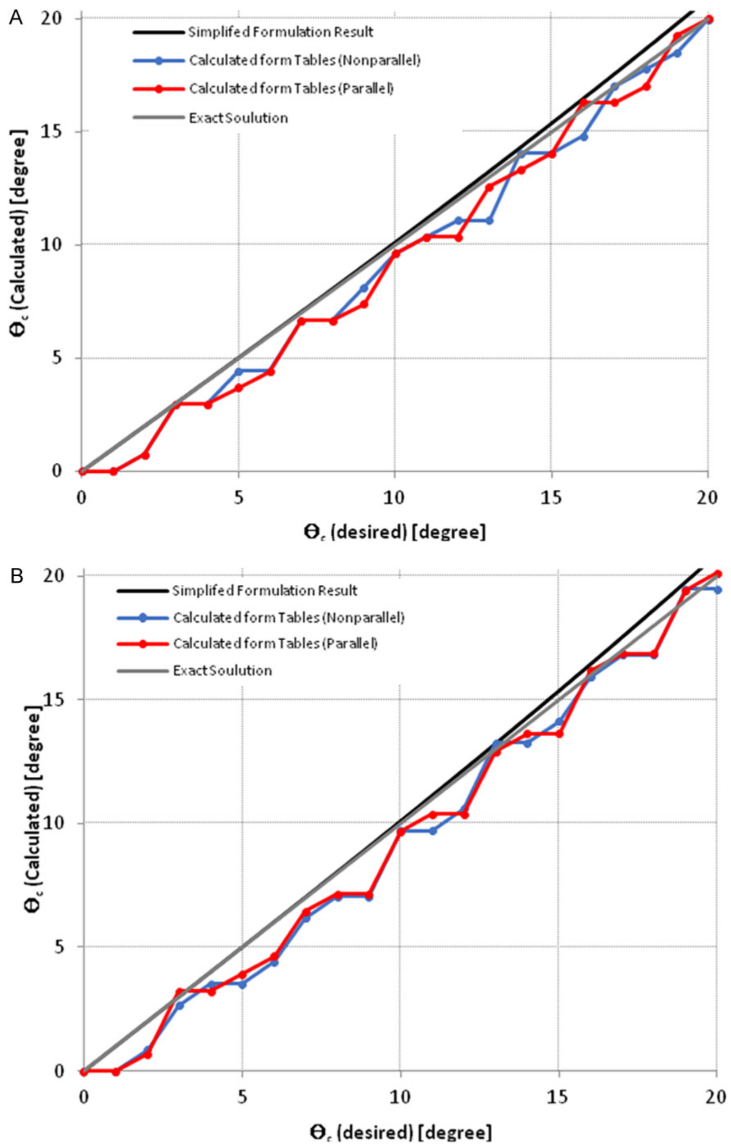

Figure 6. Comparative diagrams of different methods for varus modified angle correction from zero to 20 degrees. (A and B are related to first and second subject respectively).

ity for intrao perative adjustment of the correction. Other advantages of opening wedge osteotomy may include a more precise correction, enhancement of bone stock, the avoidance of changes in the proximal morphologic characteristics of the tibia, and the possibility of correcting large deformities. Additionally, some surgeons believe that concomitant ACL reconstruction may be easier with the medial opening wedge approach. Inherent disadvantages include the potential need to procure an autogenous bone graft and the use of an alternative bone graft source such as an allograft or a synthetic bone graft substitute [8]. New fixation devices, such as the Puddhu plate [13] and the TomoFix [13, 14], have been specifically developed for medial opening wedge osteotomies.

Although HTOs were initially performed to correct deformities in the coronal plane, opening wedge osteotomies can simultaneously alter tibial slope in the sagittal plane [5, 15, 16].

Street et al. showed that medial opening wedge osteotomy inadvertently changes posterior tibial slope. In their study on 82 knees with varus arthrosis, they found that medial opening wedge osteotomy may alter the

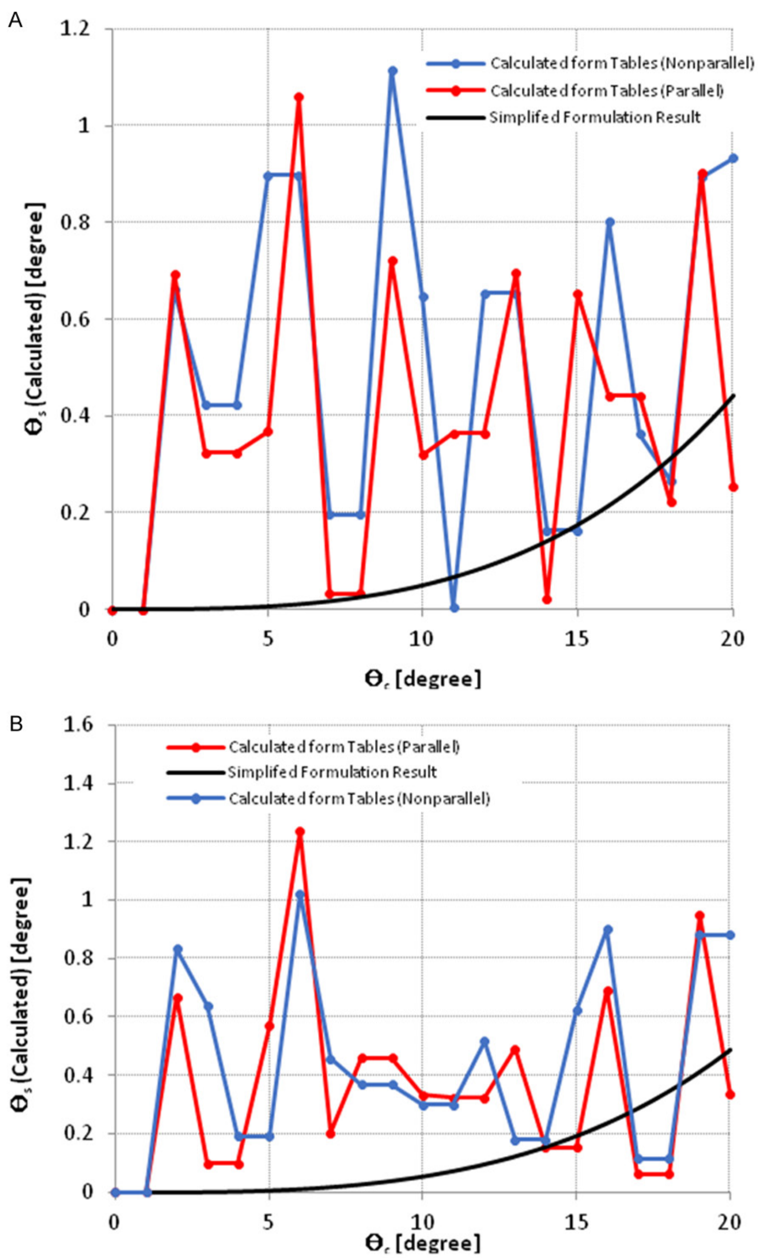

Figure 7. The comparative diagrams of changing varus angle with respect to changes of varus modified angle from zero to 20. (A and B are related to first and second subject respectively).

sagittal alignment by increasing the posterior tibial slope [17].

Many studies have been done to keep the slope unchanged in medial open wedge osteotomy, but they are not practical [18].

Song et al., in their study on forty cases of navigation-assisted open-wedge HTO, showed that in virtual surgery, a ratio of 0.67 between the anterior and posterior gap was needed to maintain the original slope [18].

In their study on proximal tibial open wedge osteotomy using triangular CT scan, Noyes et al. showed that, in order to keep the tibial slope unchanged, as a rule of thumb, the diameter of the anterior gap at the osteotomy site must be half that of the posterior gap on the posteromedial side; however, using this method, the tibial slope will change up to 1-2° [7].

All these rules are based on the assumption that, during surgery, the osteotomy line is parallel to the proximal tibial plateau [19].

Performing the osteotomy parallel to the proximal tibial plateau is an important step in the osteotomy method [19], but it is sometimes difficult to find the tibial plateau during the osteotomy. In the current study, a new osteotomy technique was considered in which a proximal tibial osteotomy was performed regardless of the proximal tibial plateau. Based on the mathematical formula, a table was introduced to facilitate the technique. Based on this study, the surgeon can measure the lengths of L_1 and L_2 intraoperatively, and using the table's data, the desired amount of correction can be achieved with less than 1.4°. The most important advantages of the method of the current study are that it does not need to consider the osteotomy line parallel to the tibial plateau and changes in the slope are minimal (mean = 0.6).

There were some limitations in this study, the first is the amount of correction desired. An amount of 10° is considered in all models. Although the technique is applicable for all

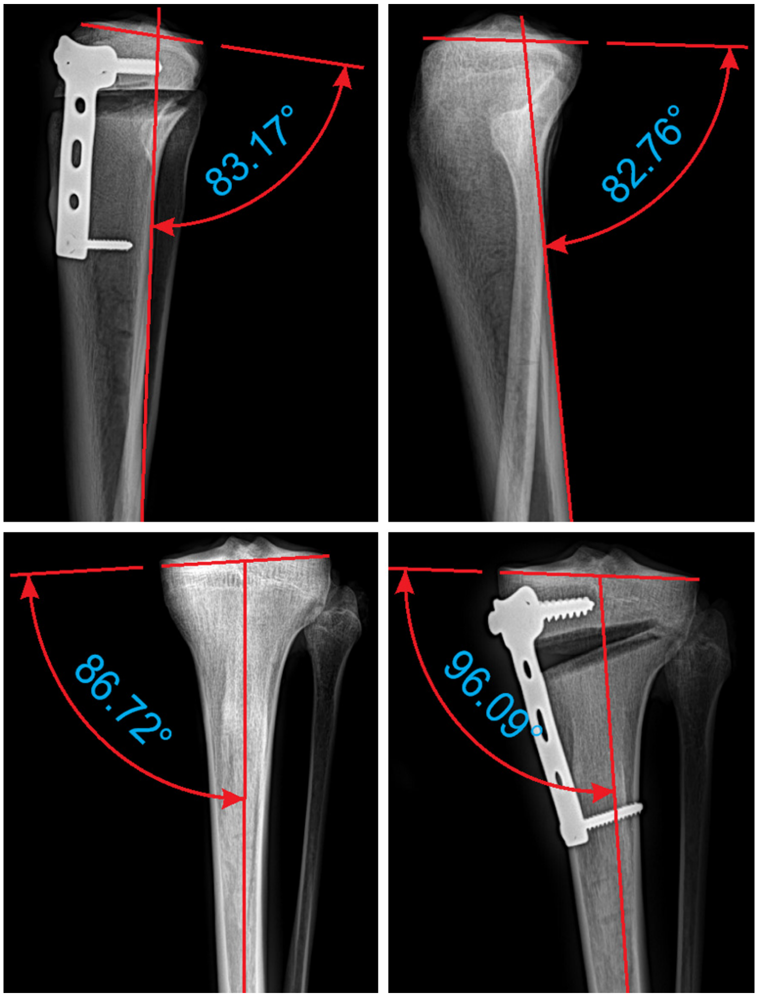

Figure 8. Change in slope angle after osteotomy (10 degree correction) in the fourth cadaveric subject.

desired degrees of correction, further cadaveric studies are needed to evaluate the technique for different varus angles.

Another limitation was the level of technical difficulty. In this method, two guide wires in the proximal tibia should reach in one point in the lateral cortex which may be challenging to the surgeon. The use of fluoroscopy and ACL guides to facilitate pin insertion is recommended, but easier methods should be investigated. A useful and fully mechanical device is invented for this aim (named OsteoGuide) by this team.

In conclusion, use of this new technique in open wedge HTO can result in good varus correction with minimal changes to the tibial slope, regardless of the orientation of the osteotomy line.

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Disclosure of conflict of interest

None.

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References

[1] Coventry MB, Ilstrup D and Wallrichs S. Proximal tibial osteotomy. J Bone Joint Surg Am 1993; 75: 196-201.
[2] Agneskirchner JD, Hurschler C, Stukenborg-Colsman C, Imhoff AB, Lobenhoffer P. Effect of high tibial flexion osteotomy on cartilage pressure and joint kinematics: a biomechanical study in human cadaveric knees. Arch Orthop Trauma Surg 2004; 124: 575-584.
[3] Bonin N, Ait Si Selmi T, Donell ST, Dejour H, Neyret P. Anterior cruciate reconstruction combined with valgus upper tibial osteotomy: 12 years follow-up. Knee 2004; 11: 431-437.
[4] FuJISAwA Y, Masuhara K and Shiomi S. The effect of high tibial osteotomy on osteoarthritis of the knee. An arthroscopic study of 54 knee joints. Orthop Clin North Am 1979; 10: 585-608.
[5] Hernigou P, Medevielle D, Debeyre J, Goutallier D. Proximal tibial osteotomy for osteoarthritis with varus deformity. A ten to thirteen-year follow-up study. J Bone Joint Surg 1987; 69: 332-354.
[6] Amendola A. Unicompartmental osteoarthritis in the active patient: the role of high tibial osteotomy. Arthroscopy 2003; 19: 109-116.
[7] Noyes FR, Goebel SX and West J. Opening wedge tibial osteotomy the 3-triangle method

to correct axial alignment and tibial slope. Am J Sports Med 2005; 33: 378-387.

[8] Koshino T, Murase T and Saito T. Medial opening-wedge high tibial osteotomy with use of porous hydroxyapatite to treat medial compartment osteoarthritis of the knee. J Bone Joint Surg 2003; 85: 78-85.

[9] Devgan A, Marya KM, Kundu ZS, Sangwan SS, Siwach RC. Medial opening wedge high tibial osteotomy for osteoarthritis of knee: long term results in 50 knees. Med J Malays 2003; 58: 62-68.

[10] Hernigou P and Ma W. Open wedge tibial osteotomy with acrylic bone cement as bone substitute. Knee 2001; 8: 103-110.

[11] Magyar G, Ahl TL, Vibe P, Toksvig-Larsen S, Lindstrand A. Open-wedge osteotomy by hemicallotasis or the closed-wedge technique for osteoarthritis of the knee A randomised study of 50 operations. J Bone Joint Surg 1999; 81: 444-448.

[12] Lobenhoffer P and Agneskirchner JD. Improvements in surgical technique of valgus high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 2003; 11: 132-138.

[13] Staubli AE, De Simoni C, Babst R, Lobenhoffer P. TomoFix: a new LCP-concept for open wedge osteotomy of the medial proximal tibia-early results in 92 cases. Injury 2003; 34: 55-62.

[14] Stoffel K, Stachowiak G and Kuster M. Open wedge high tibial osteotomy: biomechanical investigation of the modified arthrex osteotomy plate (puddu plate) and the tomofix plate. Clin Biomechan 2004; 19: 944-950.

[15] Dejour H, Neyret P, Boileau P, Donell ST. Anterior cruciate reconstruction combined with valgus tibial osteotomy. Clin Orthopaed Relat Res 1994; 299: 220-228.

[16] Giffin JR, Vogrin TM, Zantop T, Woo SL, Harner CD. Effects of increasing tibial slope on the biomechanics of the knee. Am J Sports Med 2004; 32: 376-382.

[17] Sterett WI, Miller BS, Joseph TA, Rich VJ, Bain EM. Posterior tibial slope after medial opening wedge high tibial osteotomy of the varus degenerative knee. J Knee Surg 2009; 22: 13-16.

[18] Song EK, Seon JK and Park SJ. How to avoid unintended increase of posterior slope in navigation-assisted open-wedge high tibial osteotomy. Orthopedics 2007; 30 Suppl: S127-31.

[19] Amendola A. The role of osteotomy in the multiple ligament injured knee. Arthroscopy 2003; 19: 11-13.