Poster Presentation

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The Strain Distribution on Varus Knee Corrected by Close Wedge High Tibial Osteotomy Technique versus Total Knee Replacement

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Abstract

High tibial osteotomy (HTO) was a technique to treat the varus knee to reduce the strain distribution on the medial side by shifting the mechanical axis toward the lateral side. The close wedge HTO was a choice of treatment for many years with the advantage of the bony contact at the osteotomy site. This research aim to evaluate the strain distribution on the varus knee corrected by close wedge HTO and to compare with the normal knee, varus knee and varus knee inserted total knee prosthesis under walking and stair-climbing condition by finite element analysis. The result was shown the strain distribution on the varus knee correct by close wedge HTO lower than varus knee but higher than varus knee inserted total knee prosthesis under both conditions. The varus knee inserted total knee prosthesis had the strain distribution similar to the normal knee. To preserve the ligaments, tendons and meniscus, the surgeon should be correct the varus knee with close wedge high tibial osteotomy.

Keywords: Close wedge, High Tibial Osteotomy, Total Knee Replacement and Varus Knee.

1. Introduction

Mechanical axis is a vertical line drawn from the center of the femoral head to the center of the knee joint and passes through the ankle as shown in Fig. 1.

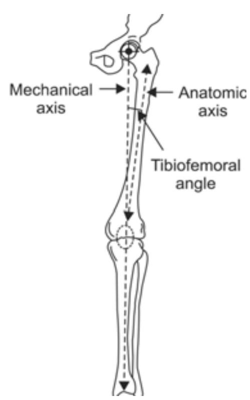


Fig.1 Mechanical axis of normal knee joint [1]

Varus knee was a malalignment of mechanical axis that shift the center of the knee joint to the lateral side of load bearing axis and the hip-knee-angle was a negative as shown in Fig. 2.

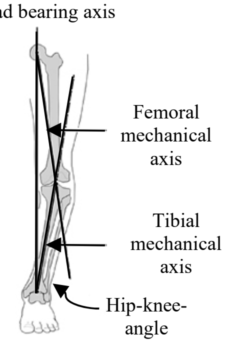


Fig. 2 Mechanical axis of varus knee [2]

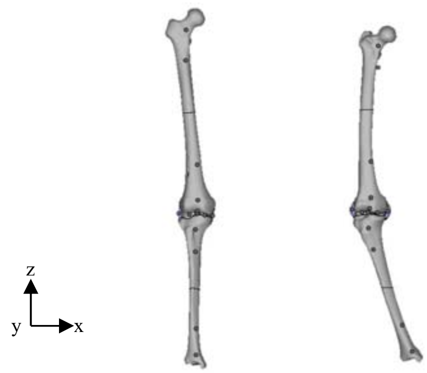
The pain in knee joint was occurred from the knee deformity as varus and valgus knee. The correction of malalignment mechanical axis at proximal tibia with a high tibial osteotomy (HTO) had a good long-term result [3-6]. This study aims to evaluate the strain distribution on the lower extremity after corrected the varus knee by close wedge HTO and to compare with the total knee replacement [7] by finite element analysis.

2. Materials and methods

2.1 Three-dimensional Model

2.1.1 Normal knee and varus knee Model

The lower extremity of normal knee and varus knee were scanned by computerized tomography (CT) scanner and was reconstructed by ITK-SNAP program. Three-dimensional models of normal knee and varus knee were shown in Fig. 3.



(a) (b)

Fig. 3 Three-dimensional models: (a) Normal knee and (b) Varus knee

2.1.2 Tibial condylar plate and screw

Tibial condylar plate was used to fix the cut proximal tibia to correct the varus knee by close wedge HTO technique. Tibial plate was scanned by CT scanner and the screw fixation was created by SolidWorks CAD software as shown in Fig. 4.

Fig. 4 Three-dimensional models of tibial condylar plate and screw fixation

2.1.3 Ligament model

The ligament to connect at the knee joint was consisted of four major ligaments as anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medial collateral ligament (MCL) and lateral collateral ligament (LCL). The meniscus was created based on the actual anatomy shape and all ligaments were created using a curve from the distal femur to the proximal tibia as shown in Fig. 5.

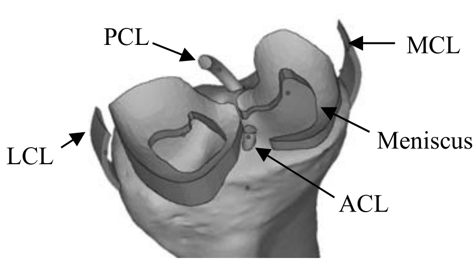


Fig. 5 The position of four ligaments and meniscus at the knee joint

2.2 Virtual simulation

This research was used the virtual simulation method to cut the proximal tibia, to correct the varus knee by mechanical axis and to insert the plate and screw fixation to fix the tibia fragment. The cut proximal tibia to correct the hip-knee-angle was shown in Fig. 6.

Fig. 6 The cut proximal tibia was corrected the hip-knee-angle

2.3 Material properties

All models in this study consisted of cortical bone, cancellous bone, four ligaments, meniscus, screw fixation, tibial condylar plate and total knee prosthesis were assumed homogeneous, isotropic and linear elastic properties [8-10]. The elastic modulus and poisson's ratio of all materials were shown in Table. 1.

Table. 1 The material properties of bone, ligaments, meniscus, screw fixation, tibial condylar plate and total knee prosthesis [11].

Materials	Elastic modulus (MPa)	Poisson's ratio
Cortical bone	14,000	0.30
Cancellous bone	600	0.20
ACL,PCL,LCL	345	0.40
MCL	332.2	0.40
Meniscus	12	0.45
Stainless	200,000	0.30
Cobalt-Chrome alloy	230,000	0.30

2.4 Loading and boundary condition

The position of muscular forces for daily activities was act on the proximal femur as shown in Fig. 7. The force magnitude separated in x-, y- and z-axis of walking and stair-climbing conditions were shown in Table. 2 and 3 respectively.

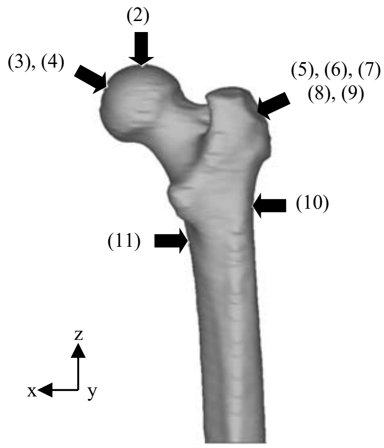


Fig. 7 The muscular force act on proximal femur

Table. 2 The muscular force act on proximal femur under walking condition [12].

Position	Force	F_x(N)	F_y(N)	F_z(N)
1	Fix displacement	0	0	0
2	Body weight	0	0	-836
3	Hip contact	-54	-32	-229.2
4	Intersegmental resultant	-8.1	-12.8	-78.2
5	Abductor	58	4.3	86.5
6	Ilio-tibial tract, proximal	0	0	0
7	Ilio-tibial tract, distal	0	0	0
8	Tensor fascia latae, proximal	7.2	11.6	13.2
9	Tensor fascia latae, distal	-0.5	-0.7	-19
10	Vastus lateralis	-0.9	18.5	-92.9
11	Vastus medialis	0	0	0

Table. 3 The muscular force act on proximal femur under stair-climbing condition [12].

Position	Force	F_x(N)	F_y(N)	F_z(N)
1	Fix displacement	0	0	0
2	Body weight	0	0	-847
3	Hip contact	-59.3	-60.6	-236.3
4	Intersegmental resultant	-13	-28	-70.1
5	Abductor	70.1	28.8	84.9
6	Ilio-tibial tract, proximal	10.5	3	12.8
7	Ilio-tibial tract, distal	-0.5	-0.8	-16.8
8	Tensor fascia latae, proximal	3.1	4.9	2.9
9	Tensor fascia latae, distal	-0.2	-0.3	-6.5
10	Vastus lateralis	-2.2	22.4	-135.1
11	Vastus medialis	-8.8	39.6	-267.1

2.5 Finite element model

All models were analyzed by finite element analysis to evaluate the equivalent of total stain distribution on normal knee, varus knee, varus knee corrected by close wedge HTO and varus knee inserted total knee prosthesis. The mesh models were built up with 4-node tetrahedral element [13] and had a total of 34,493 nodes and 138,116 elements for femur, 79,142 nodes and 353,933 elements for tibia, 1,625 node and 5,318 elements for ligaments, 1,493 nodes and 4,722 elements for meniscus and 45,332 nodes and 183,173 elements for implants. The mesh models were shown in Fig. 8.

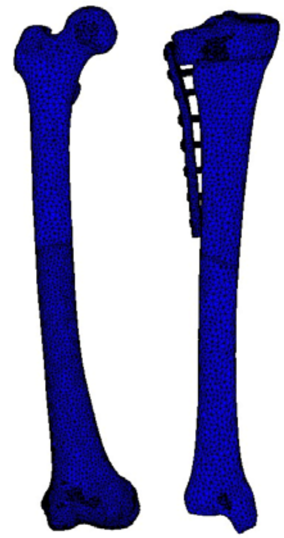


Fig. 8 Mesh model of bone-implant

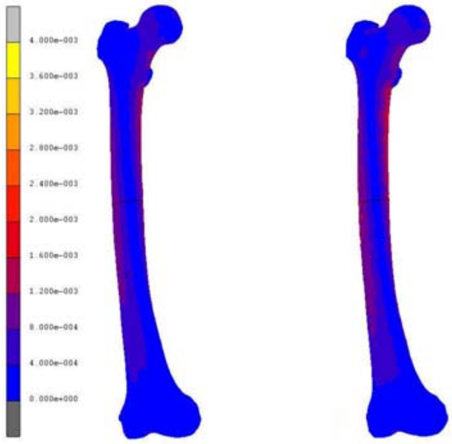
3. Result and Discussion

The maximum equivalent of total strain which occur on four models as normal knee, varus knee, varus knee inserted total knee prosthesis and varus knee corrected by close wedge HTO under walking and stair-climbing condition were shown in Table. 4.

Table. 4 The maximum equivalent of total strain on four models (με)

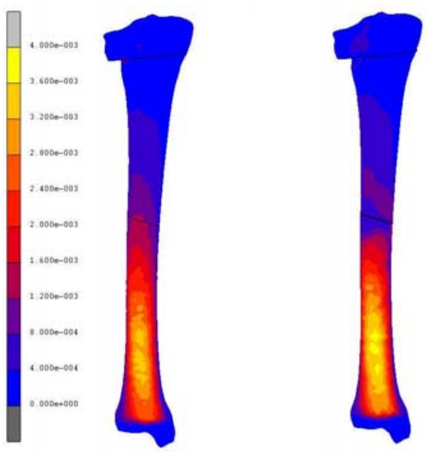
Model	The maximum equivalent of total strain (με)	
	Walking	Stair-climbing
Normal knee	1,671.19	1,690.76
Varus knee	6,916.55	8,478.03
Total knee replacement	1,692.19	1,971.49
Close wedge HTO	3,578.57	3,940.35

The maximum equivalent of total strain on the varus knee was the highest value because the malalignment of mechanical axis made the load transfer missing from the natural position. The varus knee inserted total knee prosthesis was changed the mechanical axis to the natural position by inserted the femoral component, tibia component and plastic spacer at the knee joint that help to reduce the maximum equivalent of total strain on the bone. The strain distribution on femur and tibia under walking and under stair-climbing condition were shown in Fig. 9 and 10 respectively.



(a) (b)

Fig. 9 The equivalent of total strain distribution on femur under: (a) Walking condition and (b) Stair-climbing condition



(a) (b)

Fig. 10 The equivalent of total strain distribution on tibia under: (a) Walking condition and (b) Stair-climbing condition

The close wedge HTO had reduced the maximum equivalent of total strain from the varus knee. The mechanical axis was changed to the natural position by cut and removed a piece of proximal tibia.

4. Conclusion

HTO had an averaged of a good result. It not only improved the knee function but also allowed healing of the articular cartilage. Also, no significant motion was lost as a result of the osteotomy, complications were few, and the age of the patient at the time of the osteotomy did not affect the final outcome [14]. The varus knee inserted total knee prosthesis had to remove all of four ligaments around the knee joint because the distal femur and proximal tibia had been cut and remove to adjust the mechanical axis. The maximum equivalent of total strain of four cases from minimum to maximum value was normal knee, varus knee inserted total knee prosthesis, varus knee corrected by close wedge HTO and varus knee respectively. The close wedge HTO had adjust only tibia bone but total knee arthroplasty had adjust both of femoral and tibia bone that made the varus knee inserted total knee prosthesis had the maximum equivalent of total strain near the normal knee than the other cases but the varus knee corrected by close wedge HTO had to remain the four ligaments at knee joint. To preserve the ligaments, tendons and meniscus, the surgeon should be correct the varus knee with close wedge HTO.

5. Acknowledgement

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