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The strain distribution on varus knee corrected by closing-wedge High Tibial Osteotomy (HTO) and supplemented by closing-wedge Distal Femoral Osteotomy (DFO)

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Abstract. Varus knee is a knee joint deviate from mechanical axis to the lateral side. High tibial osteotomy (HTO) was a popular technique to treat the varus knee and reduce the strain distribution by shifting the mechanical axis to the medial side. From our previous study, the varus knee correct by close wedge HTO had strain distribution lower than the varus knee but higher than the varus knee inserted total knee prosthesis under walking and stair-climbing conditions. This study aims to evaluate the strain distribution on the varus knee correct by close wedge HTO supplement DFO. The results were shown the maximum equivalent of total strain on varus knee correct by close wedge high tibial osteotomy supplement distal femoral osteotomy decreased from varus knee. The surgeon can correct the varus knee by close wedge HTO supplement DFO to preserve the ligaments, tendons and meniscus at knee joint and to reduce the maximum equivalent of total strain on the patient's lower extremity.

1. Introduction

Mechanical axis was an imaginary line to show the deform ation on lower extremity. The condition of alignment started at center of femoral head, passed thru knee joint and ended at center of ankle in normal case as shown in Figure 1.

The varus knee was a mal-alignment of mechanical axis, bending out to lateral side and had high pressure on medial side. In some case, the deformity of lower extremity was occurred on femoral bone as shown in Figure 2.

There are many methods for treat and correct the varus knee such as Total Knee Arthroplasty (TKA), High Tibial Osteotomy (HTO) and Distal Femoral Osteotomy (DFO). This study aims to evaluate the strain distribution on lower extremity corrected by close wedge high tibial osteotomy supplement distal femoral osteotomy and compare the result with varus knee corrected by total knee arthroplasty [3].

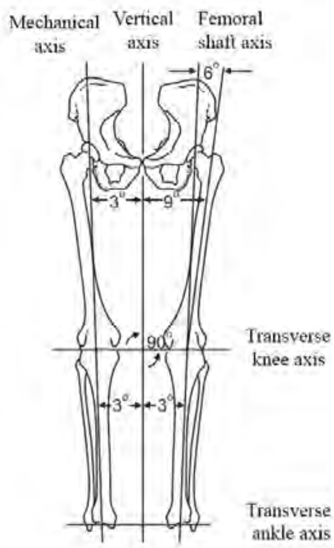


Figure 1 The relationship between mechanical axis and anatomical axis of normal lower extremity [1].

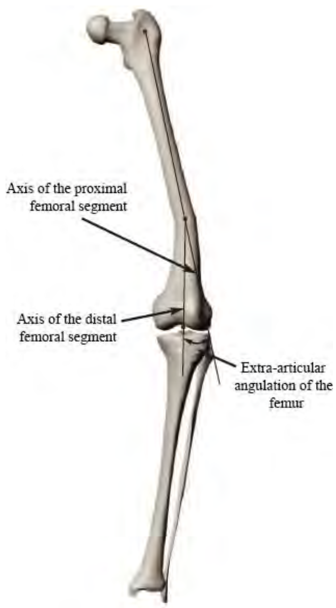


Figure 2 Extra-articular varus angulation of the femur [2].

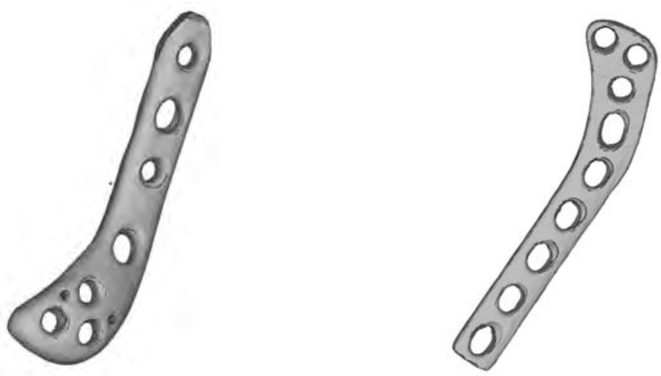
2. Materials and methods

2.1 Three-dimensional model

2.1.1 Varus knee model. Three-dimensional model of varus knee was scanned by computerized tomography (CT) scanner and was reconstructed by ITK-SNAP program. The completed model was shown in Figure 3.

2.1.2 The distal femoral plate, tibial condylar plate and screw fixation. The distal femoral and tibial condylar plate were used to fix the cut distal femur and proximal tibia respectively, was corrected the varus knee by close wedge high tibial osteotomy technique. Two plates were scanned by CT scanner and all screw fixations were created by SolidWorks CAD software with actual size as shown in Figure 4

Figure 3 Three-dimensional model of varus knee.



(a) (b)

Figure 4 Three-dimensional model of: (a) Distal femoral plate, (b) Tibial condylar plate.

2.1.3 Ligament and meniscus models. Four major ligaments were connected between distal femur and proximal tibia 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 between distal femur and proximal tibia and four ligaments were created using a curve from distal femur to proximal tibia as shown in Figure 5.

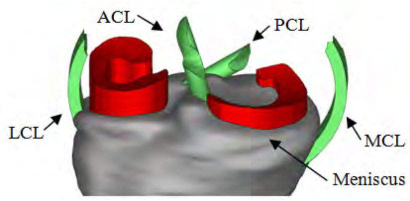


Figure 5 Three-dimensional models of four major ligaments and meniscus.

2.2 Virtual Simulation

This study was used virtual simulation method to cut proximal tibia to correct the varus knee by mechanical axis and to cut distal femur to remove angle of deformity on femoral bone. Tibial condylar plate was used to fix the cutting proximal tibia bone same as the distal femoral plate to fix the distal femoral bone. The bone model with two inserted plate was shown in Figure 6.

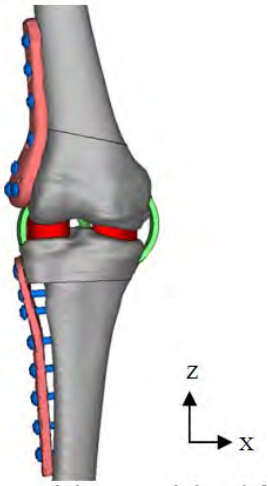


Figure 6 The bone model inserted distal femoral plate and tibial condylar plate.

2.3 Materials Properties

All models in this study, were consisted of cortical bone, cancellous bone, ligaments, meniscus, screw fixation, tibial condylar plate and distal femoral plate were assumed homogeneous, isotropic and linear elastic properties [4-6]. The elastic modulus and poisson's ratio of all materials were shown in Table. 1.

Table. 1 The materials properties of models [7].

Materials	Elastic Moldus (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

2.4 Boundary Condition

The positions of muscular forces for daily activities were operated on the proximal femur as shown in Figure 7. The force magnitude was separated in x-, y- and z-axis under walking and stair-climbing conditions were shown in Tables 2 and 3, respectively.

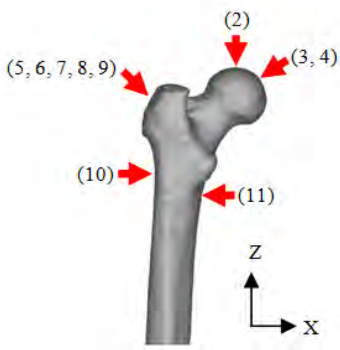


Figure 7 Position of muscular force on proximal femoral.

Table 2 The muscular force act on proximal femur under walking condition [8].

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 [8].

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

The finite element model was generated by MSC software package with four-node tetrahedral element as shown in Figure 8, was used to build up mesh model to reduce calculating time. The bone-implant model had total 165,605 nodes and 139,739 elements.

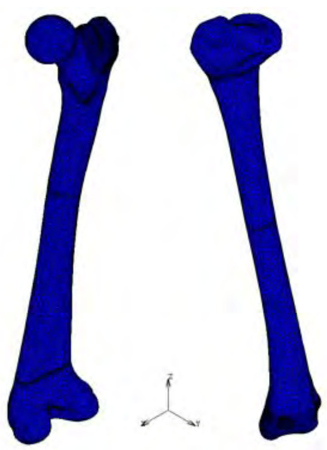


Figure 8 Mesh model of lower extremity.

3. Result and Discussions

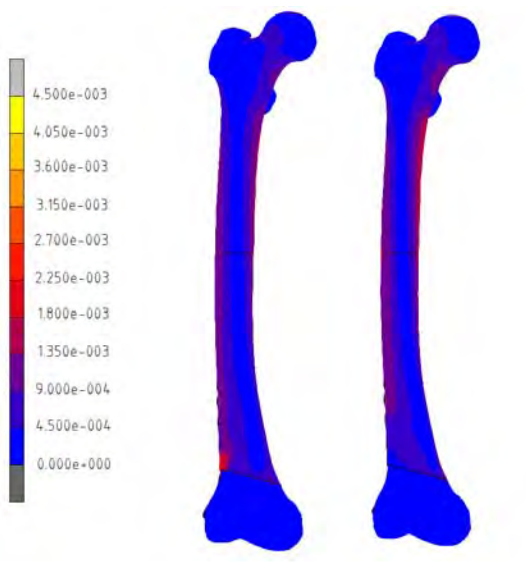
The results were shown the equivalent of total strain distribution on the bone models. The varus knee and varus knee corrected by close wedge high tibial osteotomy (HTO) supplement with distal femoral osteotomy (DFO) were simulated to compare the strain distribution with normal knee and varus knee corrected by total knee arthroplasty (TKA) from the literature [3]. The maximum equivalent of total strain on four models was 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 Arthroplasty	3695.66	3739.67
HTO Supplement DFO	5,272.14	5,392.76

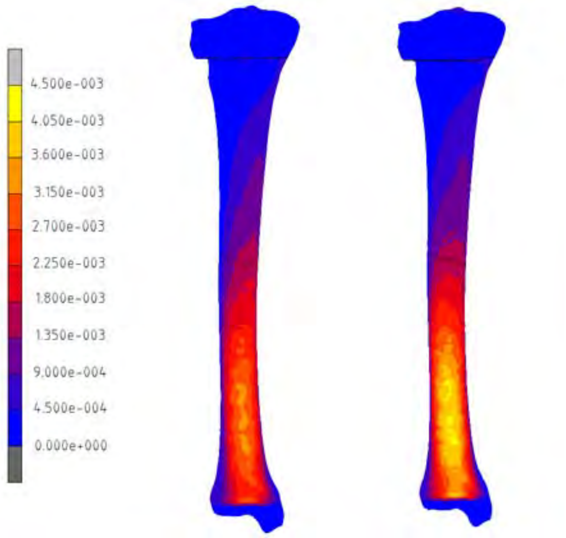
The maximum equivalent of total strain on the varus knee had the highest value because the body weight did not pass thru knee joint as mal-alignment of mechanical axis. The varus knee corrected by total knee arthroplasty was changed the mechanical axis to the natural position that helps to reduce the maximum equivalent of total strain on the bone.

The maximum equivalent of total strain for close wedge HTO supplement DFO under walking condition were 5,272.14 με on femur and 3,407.03 με on tibia and under stair-climbing condition were 5,392.76 με on femur and 4,322.51 με on tibia. The maximum values of HTO supplement DFO model were reduce from the varus knee model under both conditions because the mechanical axis was changed to natural position same as the varus knee corrected by TKA model. The strain distribution on femur and tibia for HTO supplement DFO models was shown in Figures 9 and 10, respectively.



(a) (b)

Figure 9 The strain distribution on femur under: (a) walking and (b) stair-climbing.



(a) (b)

Figure 10 The strain distribution on tibia under: (a) walking and (b) stair-climbing.

The varus knee corrected by close wedge HTO supplement DFO can reduce the maximum equivalent of total strain from varus knee but varus knee corrected by TKA had maximum equivalent of total strain near normal knee than close wedge HTO supplement DFO model. Varied degree of close wedge must be used to adjust the axis of femoral and tibia bone to reduce the maximum equivalent of total strain.

4. Conclusion

The strain distribution on varus knee corrected by close wedge HTO supplement DFO reduced from the varus model. The body weight was passed thru the adjusted mechanical axis. The strain distribution was distributed regularly at medial and lateral side on femoral bone and anterior and posterior side on tibia bone. The surgeon can correct the varus knee by close wedge HTO supplement DFO to preserve the ligaments, tendons and meniscus at knee joint and to reduce the maximum equivalent of total strain on the patient's lower extremity.

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References

[1] Du, R.H., Sahnghoon, L., Sang C.S. and Myung, C.L. (2014). Lateral closing wedge osteotomy of tibia for degenerative arthritis, *J Korean Orthop Assoc*, vol. 49(2), April 2014, pp. 95 –106.
[2] Krackow, K.A., (2008). Lower extremity alignment terminology in the measurement and analysis of axial deformity at the knee, Stryker.
[3] Aroonjarattham, P., Aroonjarattham, K. and Suvanjumrat, C. (2014). Effect of mechanical axis on strain distribution after total knee replacement, *Kasetsart (Nat. Sci.)*, vol. 48(2), November 2013, pp. 263 –282.
[4] Sitthiseripratip, K., Van Oosterwyck, H., Vander Sloten, J., Mahaisavariya, B., Bohez, E.L.J., Suwanprateeb, J. Van Audekercke, R. and Oris P., (2003). Finite element study of trochanteric gamma nail for trochanteric fracture, *Med Eng&Phy*, vol. 25, pp. 99 –106.
[5] Serala, B., Garc, J.M., Cegon, J., Doblare, M. and Serala, F. (2004). Finite element study of intramedullary osteosynthesis in the treatment of trochanteric fractures of the hip: Gamma and PFN, *J. Care Injuried*, vol. 35, pp. 130 –135.
[6] Mahaisavariya, B., Sitthiseripratip, K. and Suwanprateeb, J. (2006). Finite element study of the proximal femurwith retained trochanteric gamma nail and after removal of nail. *J. Care Injuried*, vol. 37, pp. 778–785.

[7] Peraz, A., Mahar, A., Negus, C., Newton, P. and Impelluso, T. (2008). A computational evaluation of the effect of intramedullary nail material properties on the stabilization of simulated femoral shaft fracture. *Med Eng &Phys*, vol.30, pp. 755–760.

[8] Heller, M.O., Bergmann, G., Kassi, J.P., Cales, L., Haas, N.P. and Duda, G.N. (2005). Determination of muscle loading at the hip joint for use in pre-clinical testing. *J Biomech*, vol. 38, pp. 1155–1163.