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Research Article

THE COMPARISON OF STRAIN DISTRIBUTION ON THAI NORMAL, VARUS AND TOTAL KNEE ARTHROPLASTY INSERTED FEMORAL BONE

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ABSTRACT:
Knee is the largest joint in the human body and it has been heavily used, caused to the osteoarthritis. When the knee is more degenerate, it cause pain in every movement. The treatment has several methods such as Knee Arthroscopic Surgery, High Tibial Osteotomy and Total Knee Arthroplasty. This research aims to evaluate the strain distribution on the Thai femoral bone with the normal leg, bow-leg and inserted total knee prosthesis under the daily activities, as walking and stair-climbing by finite element analysis. The results were compared the maximum equivalent of total strain on the medial and lateral side in three cases. The results showed that the ratio of strain distribution between medial and lateral side on Thai femur with normal bone, varus bone and bone inserted TKA under walking condition are 67.27%, 84.01% and 70.68% respectively; and 60.96%, 82.74% and 68.19% respectively under stair-climbing condition. After the surgery, the ratio of strain distribution on the varus femoral bone decreased and approached that of normal femoral bone.

Keywords: *Total knee arthroplasty, equivalent of total strain, finite element analysis, varus femoral bone*

1. INTRODUCTION

Knee is the largest joint in the human body. When the knee is more degenerate, it cause pain in every movement. Total Knee Arthroplasty (TKA) is a surgical procedure to treat the patients with end-stage osteoarthritis in that cannot be treated by the other. The surgeon will expose cartilage that deterioration and inserted total knee prosthesis, which made from metal and polyethylene group have been designed especially to treat osteoarthritis for replacement, then seize with the extra cement with the leg axis alignment to be made after the surgery, the patient can move the knee, walking down the weight naturally and without pain. The maximum equivalent of total strain distribution on the bone was the main cause of bone fracture [1]. The varus knee and total knee prosthesis inserted femoral bone changed strain distribution on the bone, which lead the bone fracture. This research aims to evaluate the strain distribution on the Thai femoral bone with 3 cases: the normal leg, bow-legged and inserted total knee prosthesis under the daily activities, as walking and stair-climbing by finite element analysis.

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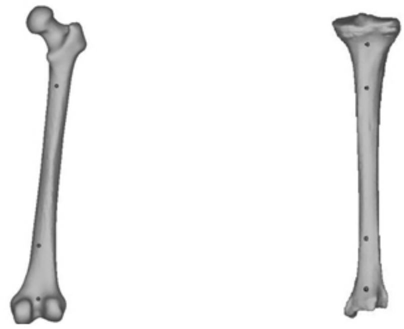
2. MATERIALS AND METHODS

2.1 The three-dimensional of femur and tibia models

The Three-dimensional models of the femur and tibia bone were process by using the Computed Tomography (CT) scan and construct the model by using ITK-SNAP for the segmentation of the three-dimensional model images and correct the image to the appropriate value. The complete model of the tight bone, which include the femur and tibia bone were shown in Fig. 1.

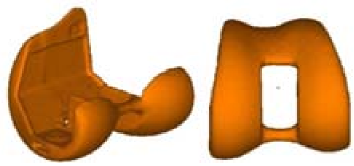


(a) Femoral bone (b) Tibia bone

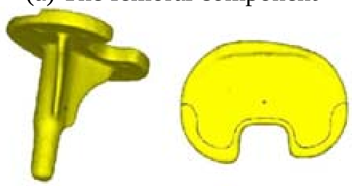
Fig. 1. The three-dimensional models of the tight bone.

2.2 Total knee prosthesis model

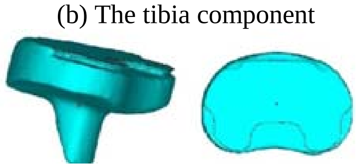
The total knee prosthesis was an implant to insert into the knee joint, which include the femoral component, the tibia component and the plastic spacer. The model was created from CT data, which is also used to create the bone model. The total knee prosthesis was shown in Fig. 2.



(a) The femoral component



(b) The tibia component



(c) The plastic spacer

Fig. 2. The three-dimensional models of knee prosthesis.

2.3 Ligament models

The ligaments at the knee joint consist of anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medial collateral ligament (MCL) and lateral collateral ligament (LCL). The 3D ligament and meniscus models are created by SolidWork 2010 software as shown in Fig. 3.

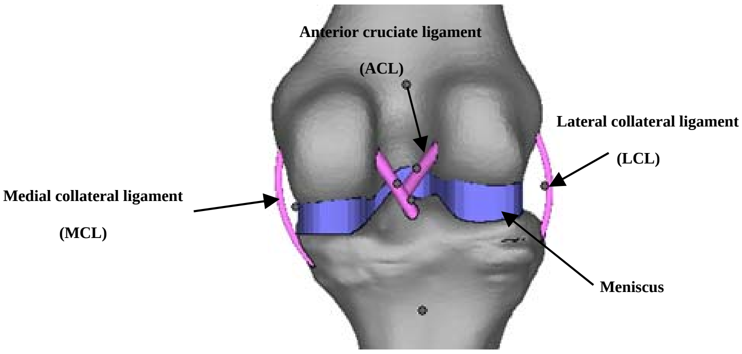


Fig. 3. The three-dimensional models of ligament and meniscus.

2.4 Virtual simulation

This research was used virtual simulation method to insert the total knee prosthesis in the knee joint with the actual surgery position at 3 degree valgus as shown in Fig. 4.

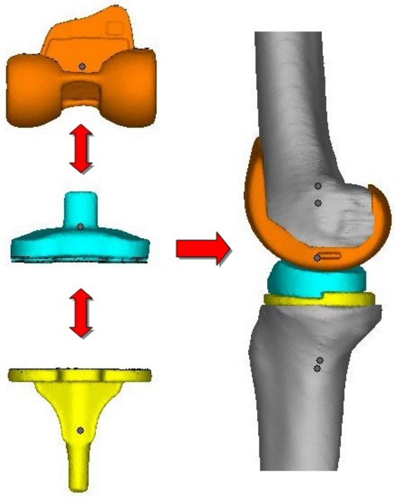
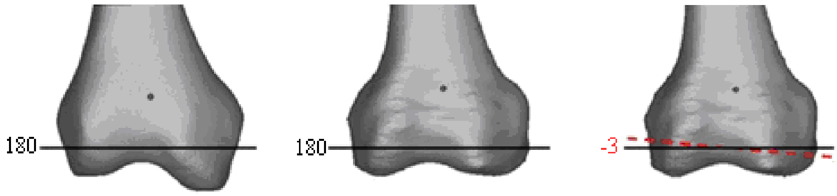


Fig. 4. The insertion of total knee prosthesis component.

The Fig. 5 was shown cutting angle of the distal femur with the condition of Thai normal femoral bone (180 degree) and 3 degree valgus angle (-3 degree) compare with Thai varus femoral bone in order to guide the treatment accuracy.



(a) Normal bone (b) Varus bone (c) -3 degree valgus angle

Fig. 5. Three models of distal femur.

2.5 Mesh generation

All models were built up with 4-node tetrahedral element. The femur had a total of 35,752 nodes and 143,322 elements. The tibia had a total of 26,203 nodes and 110,808 elements. The ligament had a total of 11,843 nodes and 47,204 elements. The implant had a total of 56,573 nodes and 245,470 elements. The mesh model was shown in Fig. 6.

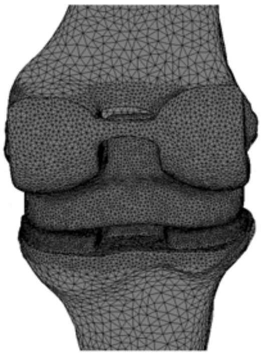


Fig. 6. The mesh model of ligament and meniscus in Thai normal femoral bone.

2.6 Material properties

Materials properties of cortical bone, cancellous bone, ligament and total knee prosthesis were assumed to be homogeneous, isotropic and linear elastic as shown in the Table. 1.

Table 1: The materials properties of bone, ligament and prostheses [2-4].

Material	Elastic modulus (MPa)	Poisson's Ratio
Cortical bone	14,000	0.30
Cancellous bone	600	0.20
Menicus	12	0.45
ACL,PCL,LCL	345	0.40
MCL	332.2	0.40
Titanium	110,000	0.30
Cobalt-Chrome alloy	230,000	0.30

2.7 Loading and boundary conditions

The muscles loading at the hip joint for the activities of walking and stair-climbing conditions were derived from Heller M.O., *et al* [5]. The force of body weight was transmitted from the proximal to the distal part and the muscular force act on the proximal femoral bone as shown in Fig. 7. The magnitude of muscular force under walking and stair-climbing condition was shown in Table. 2 and 3 respectively.

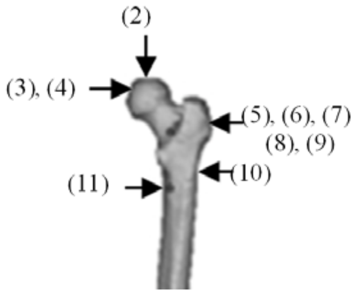


Fig. 7. The point of muscles loading was act at the femoral bone.

Table 2: The muscular force act on proximal femur under walking condition [5].

Position	Force	F_x (N)	F_y (N)	F_z (N)
1	Fix	-	-	-
2	Body weight	-	-	-836.0
3	Hip contact	-54.0	-32.8	-229.2
4	Intersegmental resultant	-8.1	-12.8	-78.2
5	Aboductor	58.0	4.3	86.5
8	Tensor fascia, Proximal	7.2	11.6	13.2
9	Tensor fascia, Distal	-0.5	-0.7	-19.0
10	Vastus lateralis	-0.9	18.5	-92.9

Table 3: The muscular force act on proximal femur under stair-climbing condition [5].

Position	Force	F_x (N)	F_y (N)	F_z (N)
1	Fix	-	-	-
2	Body weight	-	-	-847.0
3	Hip contact	-59.3	-60.6	-236.3
4	Intersegmental resultant	-13.0	-28.0	-70.1
5	Aboductor	70.1	28.8	84.9
6	Ilio-tibial tract, Proximal	10.5	3.0	12.8
7	Ilio-tibial tract, Distal	-0.5	-0.8	-16.8
8	Tensor fascia, Proximal	3.1	4.9	2.9
9	Tensor fascia, 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

2.8 Finite element model

All models, which were used in this research, were created mesh model by MSC. Software and were analyzed by the finite element method to evaluate the maximum equivalent of total strain on the medial and lateral side of Thai normal bone, varus bone and TKA inserted femoral bone at 3 degree valgus of mechanical axis, to compare the value. The 3 degree valgus of TKA was a popular position in surgery for long lifetime.

The mechanical axis of the femur in the frontal plane was defined with the marker at the anterior superior iliac spines (ASIS) on pelvic as shown in Fig.8 and the virtual marker at the knee joint center (defined as the midpoint between the lateral and medial femoral condyles) and the mechanical axis of the tibia was defined with the virtual marker at the ankle knee joint center (defined as the midpoint of the lateral and medial malleoli) [6]. The mechanical axis was shown in Fig. 9 and the mechanical axis of three models were analyzed in this research were shown in Fig. 10.

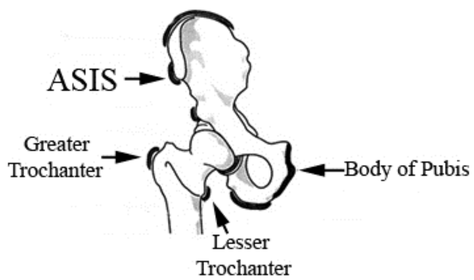


Fig. 8. The anterior superior iliac spines (ASIS) [7].

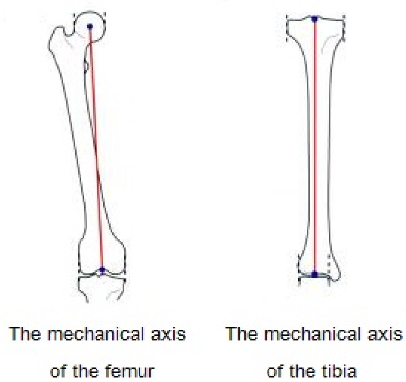


Fig. 9. The mechanical axis of the femur and the mechanical axis of the tibia [8].

(a) The normal femoral bone (b) The bow-legged with knee varus (c) The bone inserted TKA at 3 degree valgus

Fig. 10. The mechanical axis of three models.

3. Results

The results of finite element analysis were calculated by the MSC software package. To analyzed the equivalent of total strain distribution on the femoral bone for three difference model under condition of walking and stair-climbing activities.

3.1 Lateral side of the femur

The maximum equivalent of total strain on the lateral side in condition of three different models under the daily activities was shown in Table. 4 and Fig. 11.

Table 4: The maximum equivalent of total strain on the lateral side (microstrain).

Model	Equivalent of total strain (microstrain)	
	Walking	Stair-climbing
Normal	675.89	713.80
Knee varus	1,588.44	1,807.92
3° valgus	1,006.84	1,141.43

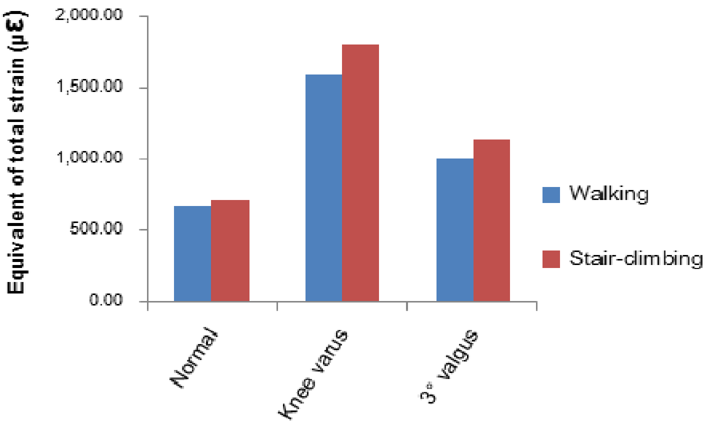


Fig. 11. The maximum equivalent of total strain on the lateral side under walking and stair-climbing condition.

3.2 Medial side of the femur

The maximum equivalent of total strain on the medial side in condition of three different models under the daily activities was shown in Table. 5 and Fig. 12.

Table 5: The maximum equivalent of total strain on the medial side (microstrain).

Model	Equivalent of total strain (microstrain)	
	Walking	Stair-climbing
Normal	1,004.75	1,170.89
Knee varus	1,890.80	2,185.05
3° valgus	1,424.47	1,673.88

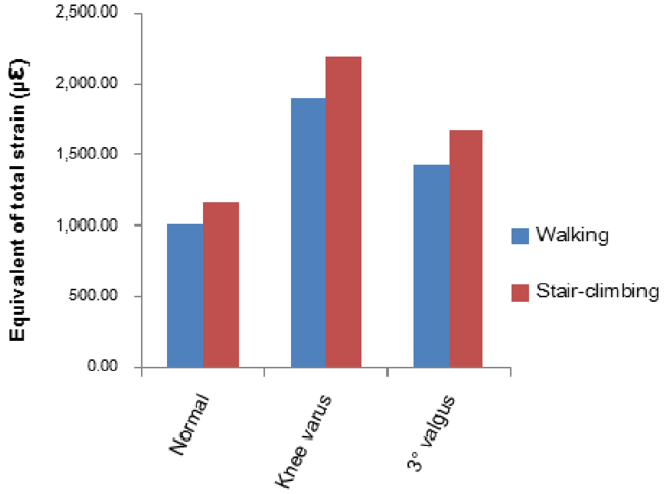


Fig. 12. The maximum equivalent of total strain on the medial side under walking and stair-climbing condition.

4. Discussion

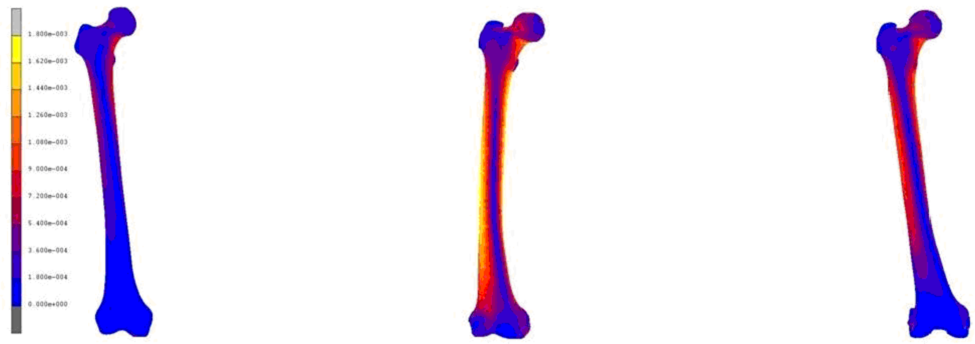
The position of the prosthesis in 3 degree valgus of the mechanical axis had the ratio of the strain distribution between medial and lateral side similar to the ratio of strain distribution between medial and lateral side of the normal bone.

The ratio of equivalent of total strain distribution between lateral side and medial side at femoral shaft, which affect the bone strength, was defined by equation (1)

$$\textit{The ratio of equivalent of total strain distribution} = \frac{\textit{strain distribution on lateral side}}{\textit{strain distribution on medial side}} \times 100\% \quad (1)$$

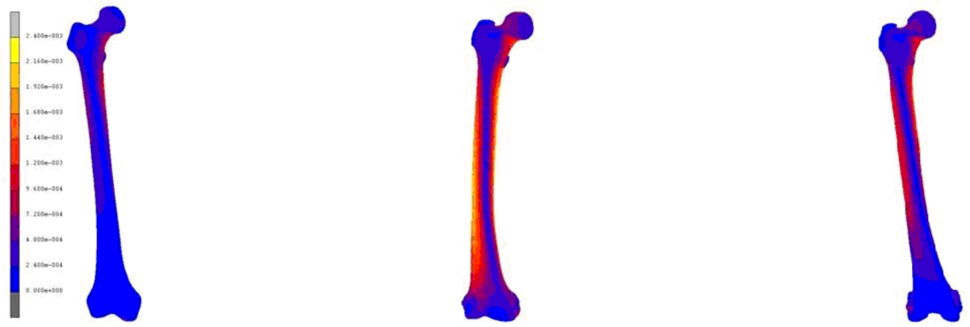
- Normal leg had 67.27% under walking condition and 60.96% under stair-climbing condition.
- Leg with varus knee has 84.01% under walking condition and 82.74% under stair-climbing condition. Varus knee had strain distribution higher than the normal leg because the mechanical axis did not occur at natural position.
- Leg with knee prosthesis had 70.68% under walking condition and 68.19% and stair-climbing condition. The strain distribution decrease from the varus knee condition and the strain came to close to the case of normal bone.

The strain distribution on the femoral bone of three models was shown in Fig. 13-14 under walking and stair-climbing condition respectively.



(a) Normal leg (b) Leg with varus knee (c) Leg with knee prosthesis 3 degree valgus

Fig. 13. The equivalent of total strain on femoral shaft under walking condition.



(a) Normal leg (b) Leg with varus knee (c) Leg with knee prosthesis 3 degree valgus

Fig. 14. The equivalent of total strain on femoral shaft under stair-climbing condition.

5. Conclusions

The results of finite element analysis were shown the strain distribution on three cases of Thai femur: normal bone, varus bone and bone inserted TKA, which was set the position of the prosthesis at 3 degree valgus. The treatment of inserted TKA in the patient with varus knee had help to decrease the strain on the bone close to the normal bone. The further work will intend to evaluate the strain distribution in the patient with osteoarthritis of the knee with the corrected axis running through the Fujisawa Point [9].

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