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The Comparison of Strain Distribution on Thai Normal, Varus and Total Knee Arthroplasty-Inserted Femoral Bone the 4th TSME Conference on Mechanical Engineering (TSME-ICoME)

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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.

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.

2. Materials and Methods

2.1 Three-dimensional Model

2.1.1 Femur and Tibia model

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.

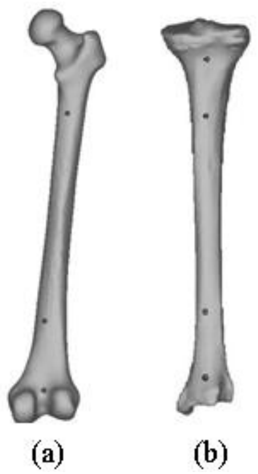

Fig. 1 Show the 3D models of the tight bone: (a) Femoral bone and (b) Tibia bone.

2.1.2 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.

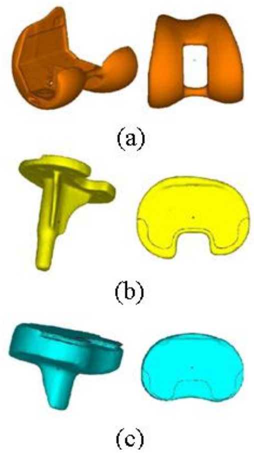

Fig. 2 Show the 3D models of knee prosthesis: (a) The femoral component, (b) The tibia component and (c) The plastic spacer.

2.1.3 Ligament model

The ligaments at the knee joint consist of anterior collateral ligament (ACL), posterior collateral 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.

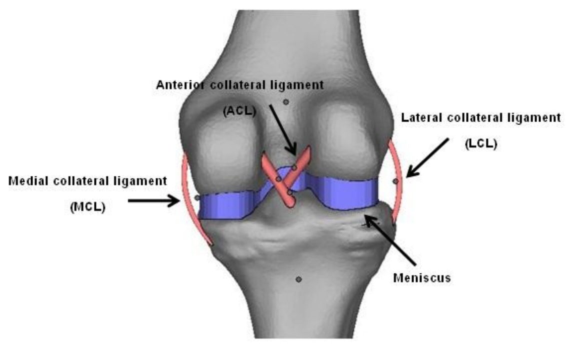

Fig. 3 Show the 3D models of ligament and meniscus.

2.2 Virtual simulation

This research was used the 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.

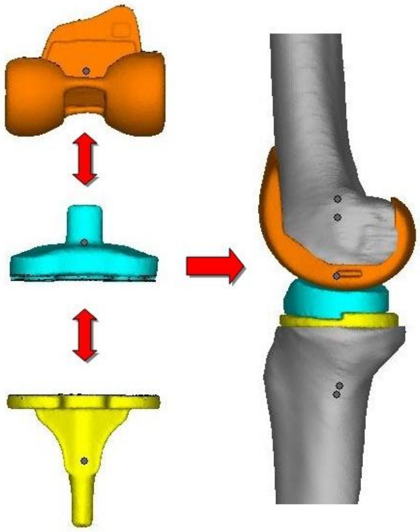

Fig. 4 Show the insertion of total knee prosthesis component.

The Fig. 5 was shown the 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

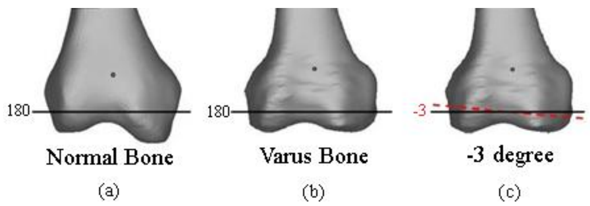

Fig. 5 Show the three models of distal femur with (a) Normal bone, (b) Varus bone and (c) -3 degree valgus angle

2.3 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.

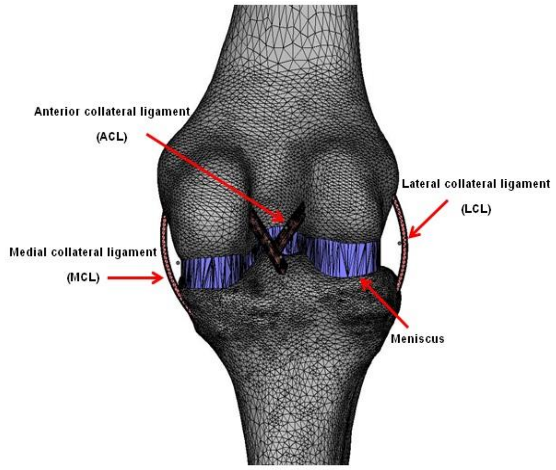

Fig. 6 Show the mesh model of ligament and meniscus in Thai normal femoral bone.

2.4 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 [1-3].

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

2.5 Loading and boundary condition

The muscles loading at the hip joint for the activities of walking and stair-climbing conditions were derived from Heller M.O., et al [4]. 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.

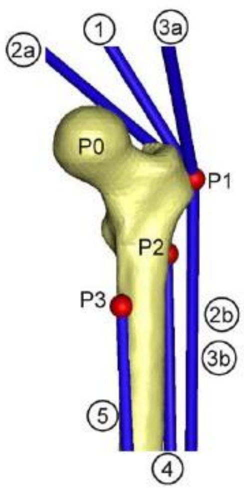

Fig. 7 Shown the point of muscles loading were act at the femoral bone. [4]

2.6 Finite element model

All models, which were used in this research, 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 mechanical axis of the femur in the frontal plane was defined with the marker at the anterior superior iliac spines (ASIS) was 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) [5]. 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.

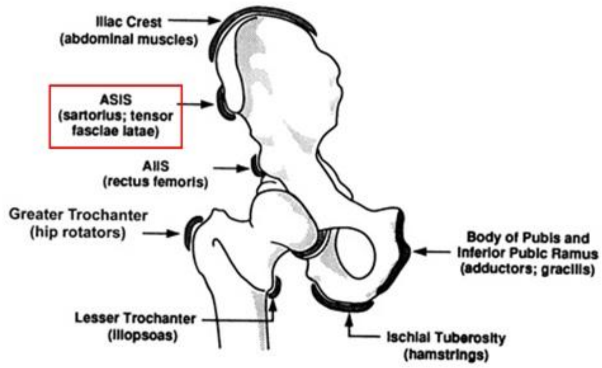

Fig. 8 Show the anterior superior iliac spines (ASIS). [6]

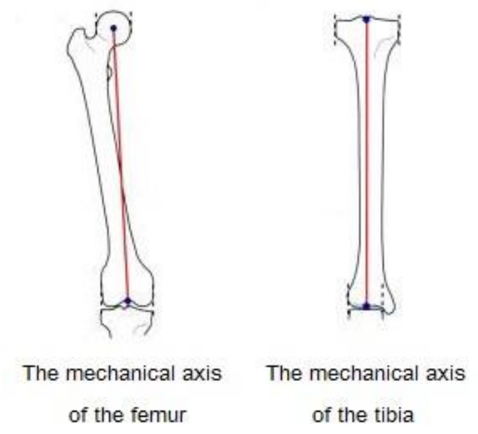

Fig. 9 Show the mechanical axis of the femur and the mechanical axis of the tibia. [7]

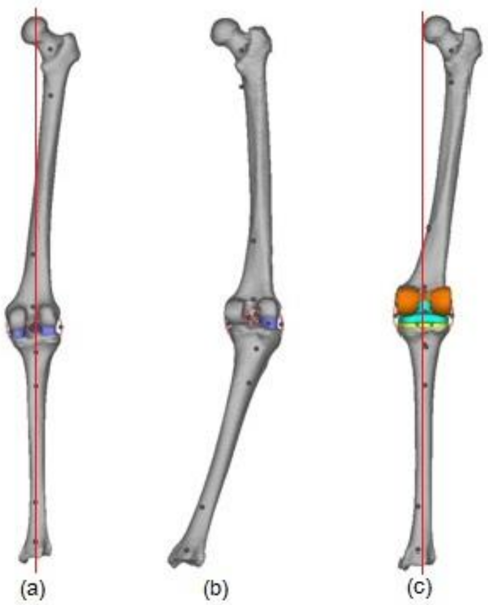

Fig. 10 Show the mechanical axis of three models: (a) The normal femoral bone, (b) The bow-legged with knee varus and (c) The bone inserted TKA at 3 degree valgus.

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. 2 and Fig. 11.

Table. 2 The maximum equivalent of total strain on the lateral side (με).

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

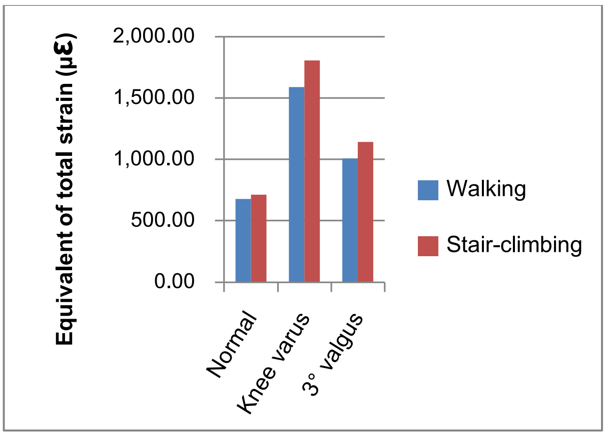

Fig. 11 Show the maximum equivalent of total strain on the lateral side under walking and stair-climbing condition.

3.2 Femoral medial side

The maximum equivalent of total strain on the medial side in condition of three different models under the daily activities was shown in Table. 3 and Fig. 12.

Table. 3 The maximum equivalent of total strain on the medial side (µƐ).

Model	Equivalent of total strain (µƐ)	
	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

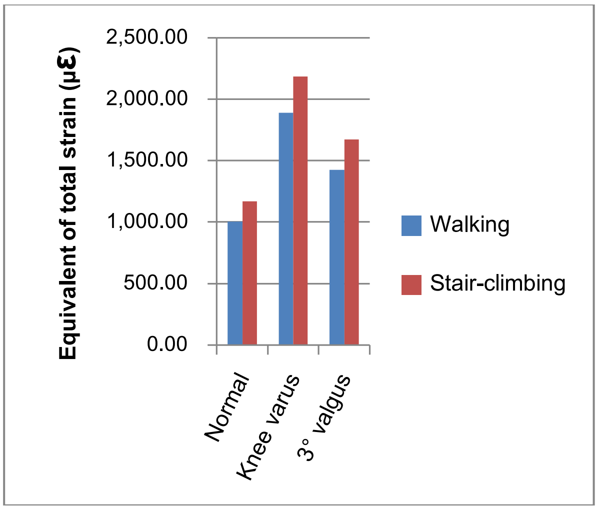

Fig. 12 Show the maximum equivalent of total strain on the medial side under walking and stair-climbing condition.

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 of normal leg model had 67.27% under walking condition and 60.96% under stair-climbing condition, when compared to the model of leg with varus knee has 84.01% under walking condition and 82.74% under stair-climbing condition, was found the varus knee had strain distribution higher than the normal leg because the mechanical axis did not occur at natural position. The model of leg with knee prosthesis had the ratio of equivalent of total strain distribution 70.68% and 68.19% under walking condition and stair-climbing condition, which was shown 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.

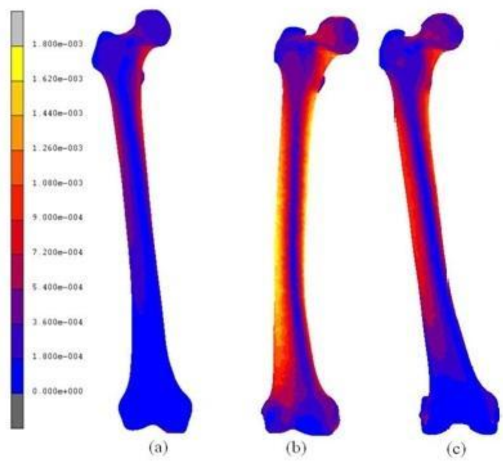

Fig. 13 Shown the equivalent of total strain on femoral shaft under walking condition: (a) Normal leg, (b) Leg with varus knee and (c) Leg with knee prosthesis 3 degree valgus.

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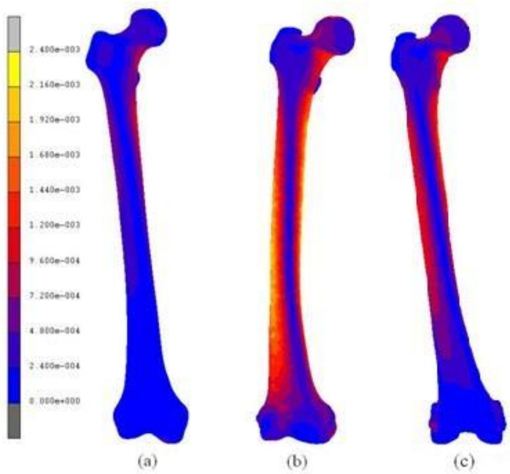

Fig. 14 Shown the equivalent of total strain on femoral shaft under stair-climbing condition: (a) Normal leg, (b) Leg with varus knee and (c) Leg with knee prosthesis 3 degree valgus.

5. Conclusion

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' [8].

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7. References

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