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The evaluation of labral repair affect hip joint by finite element analysis

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Abstract. Acetabular labrum was a connective tissue around hip joint, which connected pelvis to femur. The laceration on labrum can be evoked by accident or excessive using of hip joint and can be repaired by surgical technic as suture. This study was constructed the three-dimensional bone model from CT data and the connective tissue as cartilage and acetabular labrum from SolidWorks software. Labrum was divided to intact and repair conditions. The repair condition was tightened the labral ring and reduced their thickness. The compressive force was act on the hip model. Contact force on cartilage in hip socket was analyzed and validated with the hip simulator machine. The result was shown the mean contact force on cartilage from simulation differ from simulator machine 25.88% under intact labrum and 19.40% under repair labrum. Reducing of labrum thickness did not affect the mean contact force on cartilage in hip socket.

1. Introduction

Hip was a ball and socket joint, which linked pelvis and femur. Many types of connective tissue composed in hip joint as bone cartilage labrum. Acetabular labrum was a ring of fibrocartilage around hip joint to seal the synovial fluid, which was lubricated the joint as show in Figure 1. Labrum had a significant for receive the contact stress in hip joint [1] and transfer the loads from pelvis to femur. Laceration on labrum can be evoked by accident or excessive using of hip joint that may effect to the hip stability. Smith et al., (2011) had reported the radial tears decreased the strain on labrum against the intact condition [2]. Arthroscopy and suture anchor were useful for narrow space as hip joint surgery [3, 4]. Labrum may be re-established their function by repair of torn condition by suture [5]. During the surgery process, torn labrum had removed and the suture was tightened labral ring that change in the labral shape as show in Figure 2 [6]. Changed the labral shape affect the hip function and stability. Labrum with acetabular dysplasia had to carry the larger load than the normal [7]. Philippon et al., (2014) had measured intra-articular fluid pressure of hip joint. Labral repair provided 102% mean fluid pressure relative to intact labrum [8]. Nepple et al., (2014) had reported the resistance of hip fluid seal to distraction. Eighty four percentages of intact labrum distraction force was used to distract the labral repair condition [9]. This study aims to evaluate the labral repair affect hip joint by finite element analysis. Labrum was divided to intact and repair conditions. The repair condition was tightened the labral ring and reduced their thickness.

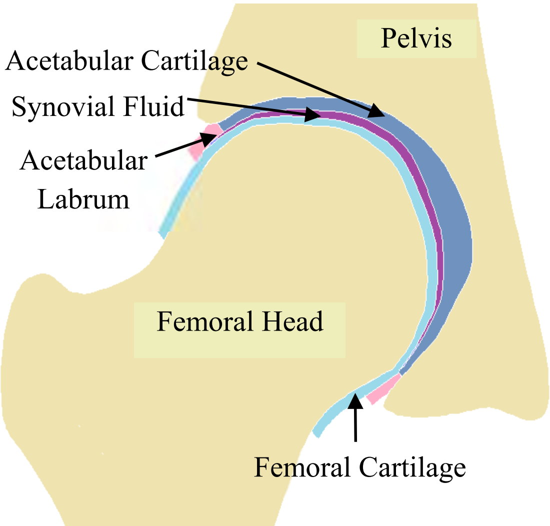


Figure 1. Cross section of hip joint.

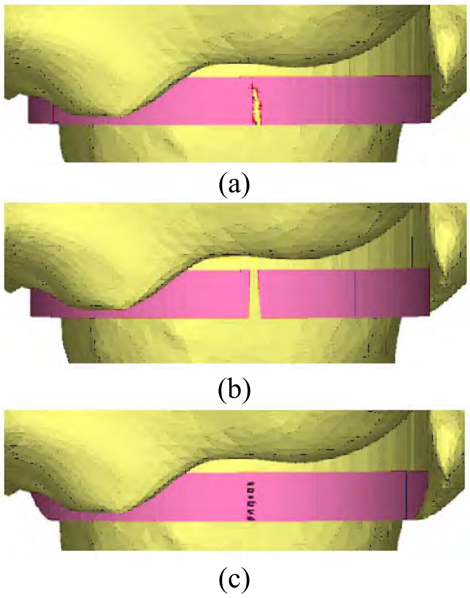


Figure 2. Characteristic of acetabular labrum: (a) Torn labrum, (b) Tear removal and (c) Labral repair.

2. Methods

Three-dimensional bone model was scanned by computerized tomography scanner (CT scanner) and reconstructed by ITK-SNAP program. Hip models were consisted of pelvis and femur as show in Figure 3. Main Text Body All connective tissue as labrum, acetabular cartilage and femoral cartilage were created from SolidWorks software based on anatomical position and shape. Three-dimensional hip bone model was completed with connective tissue as shown in Figure 4.

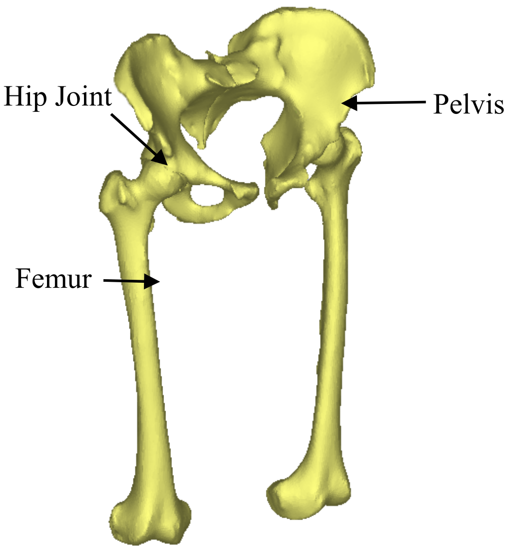


Figure 3. Three-dimensional bone model.

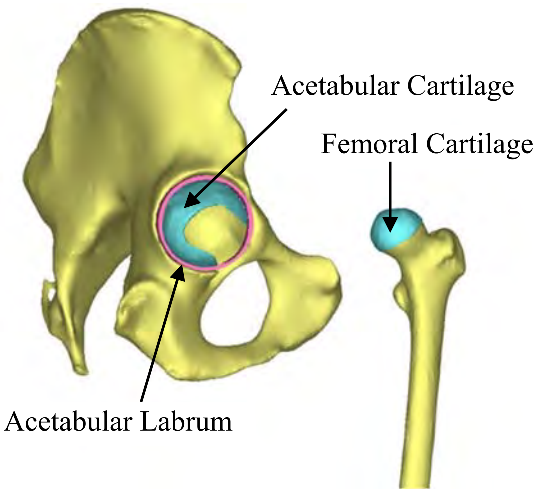
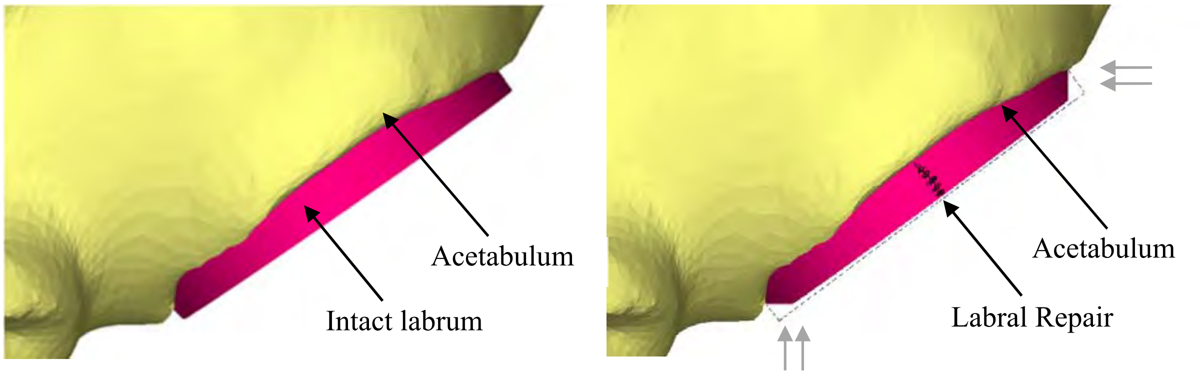


Figure 4. The connective tissue on bone model.

Two conditions of labrum were used in this study including intact labrum and labral repair as shown in Figure 5. The repair condition was tightened the labral ring and reduced their thickness.



(a) (b)

Figure 5. Two conditions of labrum: (a) Intact labrum and (b) Thickness decrease of labrum repair.

The four-node tetrahedral elements were used to generate the mesh model by MSC software. The hip model had total of 108,271 nodes and 443,333 elements for intact model and 109,131 nodes and 445,775 elements for labral repair model. All materials involved in the model were assumed homogeneous, isotropic and linear elastic as shown in Table 1.

Table 1. Material properties of bone and hip joint component [10-12].

Material	Elastic modulus (MPa)	Poisson's ratio
Cortical bone	17,000	0.29
Cancellous bone	600	0.2
Cartilage	11.63	0.45
Labrum tissue	33	0.478

Boundary condition was defined according to the experiment testing, was tested by hip simulator machine under condition as follow:

- Pelvis was compressed with axial load 350 N at the middle position.
- Pelvis was fixed rotation. Load only had influence on axial deformation.
- End of distal femur was fixed as shown in Figure 6 [13].
- Stress distribution on cartilage was observed and strain distribution on bone and labrum was remarked.

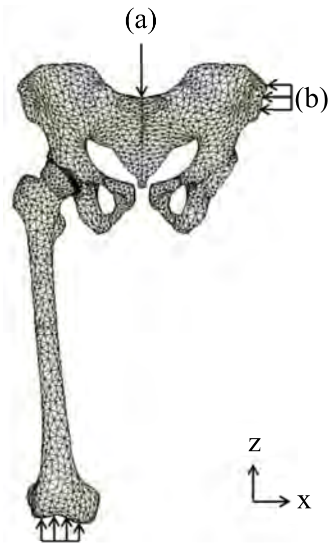


Figure 6. The position of forces on bone model:
(a) Compressive axial load 350 N (b) Rotational fix on pelvis and (c) Distal femoral fix.

3. Results

The results were shown the equivalent of total strain distribution on connective tissue under intact labrum and labral repair conditions. The maximum and mean equivalent of total strain was shown in Table 2 and Figures 7 - 9 were shown the strain distribution on actabular cartilage, femoral cartilage and acetabular labrum respectively.

Table 2. The maximum and mean equivalent of total strain on hip bone's connective tissue.

Model	Equivalent of total strain (microstrains)			
	Intact labrum		Labral repair	
	Max	Mean	Max	Mean
Acetabular cartilage	97,371	8,988	97,760	9,368
Femoral cartilage	82,590	5,512	81,919	5,506
Acetabular labrum	27,371	2,476	23,413	3,001

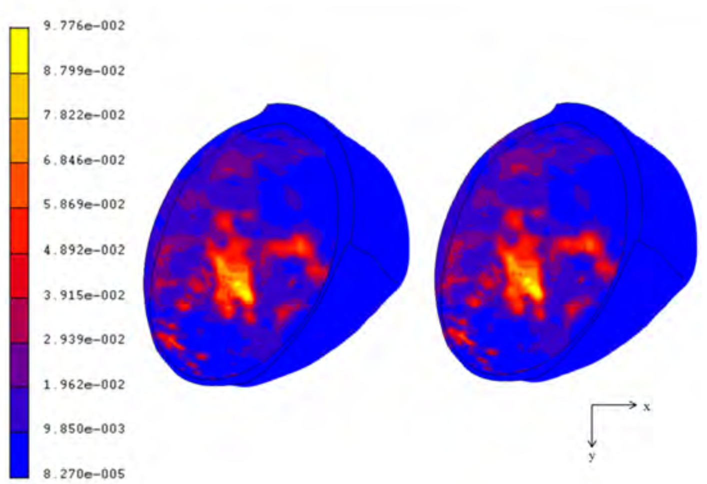


Figure 7. The strain distribution on actabular cartilage with intact labrum (left) and labral repair (right).

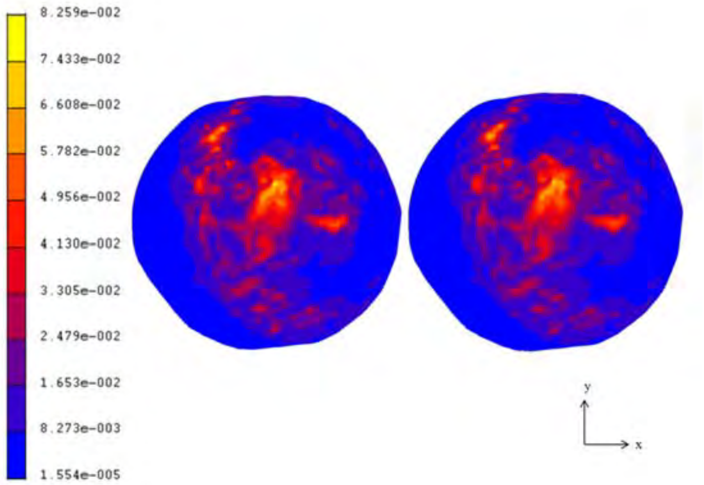


Figure 8. The strain distribution on femoral cartilage with intact labrum (left) and labral repair (right).

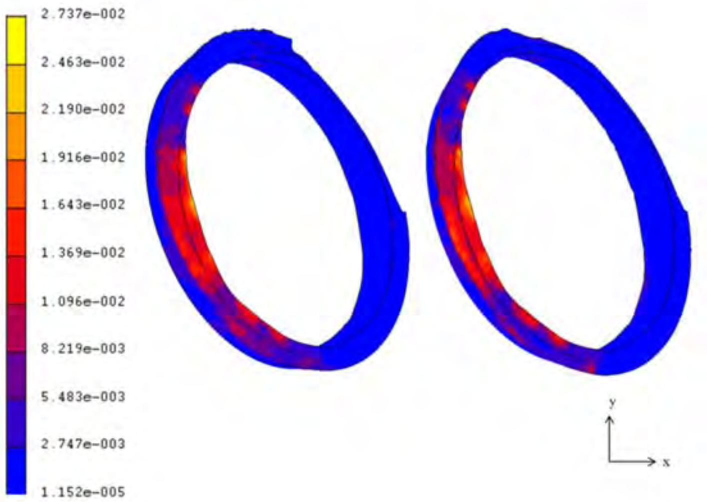


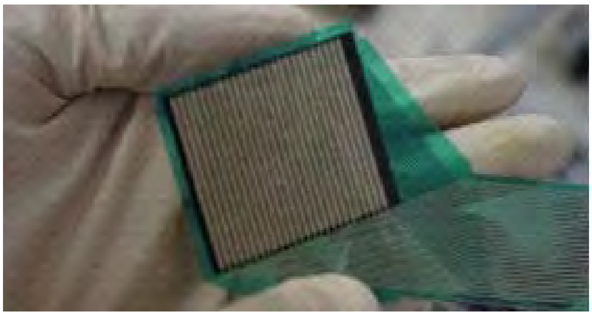
Figure 9. The strain distribution on acetabular labrum with intact labrum (left) and labral repair (right).

The maximum equivalent of total strain on pelvis and femur was 1,946 and 228 microstrains under intact labrum and labral repair condition, did not exceed 25,000 microstrains that made the bone fracture [14, 15]. The higher strain distribution under labral repair than the intact condition did not affect another part of hip joint but the concentrate strain can cause the labrum tear. Circumspection activities need for the patient after surgery.

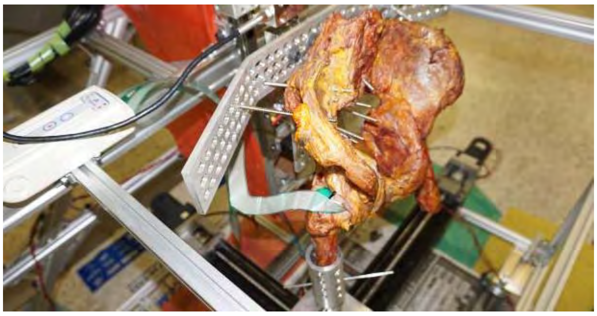
4. Experimental Testing

In this study, the hip bone model was validated with the experiment results. Hip simulator machine was used for the experimental testing. Cadaveric hip part including pelvis and femur was compressed under vertical force 350 N as shown in Figure 10. One of the experimental results was a contact force between acetabular cartilage surface and femoral cartilage. After the load was applied, contact force between two surfaces was measured by Tekscan I-ScanTM model 4000 sensor as shown in Figure. 11.

Figure 10. Hip simulator machine.



(a)



(b)

Figure 11. The shape and position of force sensor: (a) Tekscan I-ScanTM model 4000 and (b) Hip contact force measurement.

In experimental testing, the contact force of hip joint was recorded in two conditions of labrum. The first was intact labrum as shown in Figure 12 and the other was labral repair, which some of labrum as torn labrum was removed and the labrum was sutured to repair the tear as shown in Figure 13. The cadaveric model was pressed under vertical 350 N same as the simulation model that given the contact force under intact labrum and condition labral repair condition was 279.48±27.53 and 294.84±40.81 N respectively. In the same way, the experimental sensor also measured contact area between two surfaces of cartilage, intact labrum provided 641 mm^2 of contact area and labral repair provided 648 mm^2.

Figure 12. Cadaveric hip with intact labrum.

Figure 13. Suture repair of labrum tear.

5. Discussion

The simulation model showed the contact normal force between acetabular cartilage surface and femoral cartilage was 351.81 N and 352.05 N under intact labrum and labral repair respectively. The results were shown the mean contact force on cartilage from simulation as show in Figure 14 differ from hip simulator machine 25.88% under intact labrum and 19.40% under repair labrum. Also most of experimental cadaveric had a same trends that mean the contact force in labral repair condition similar to intact labrum.

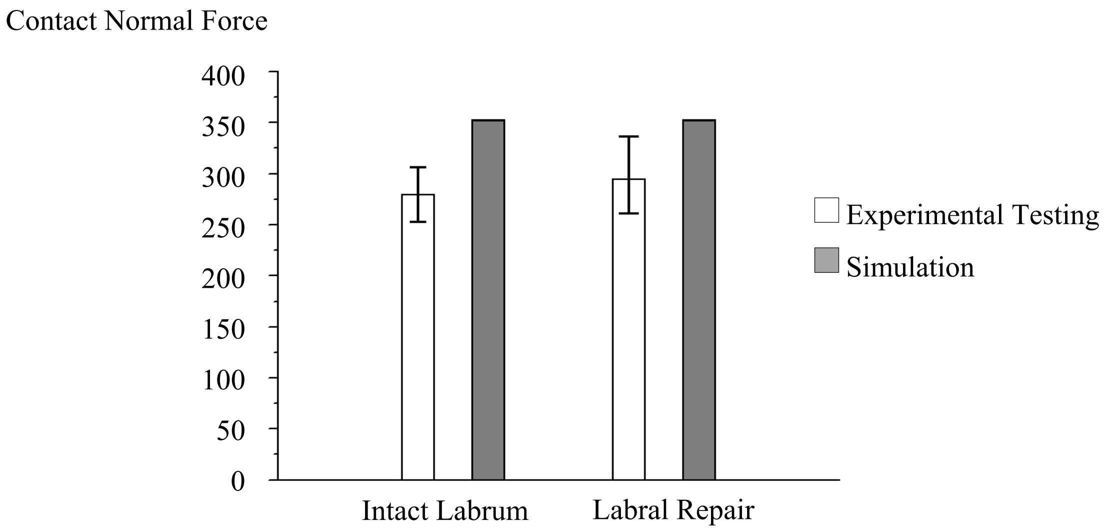


Figure 14. Experimental testing and simulation result.

In this simplify hip bone model, all biomaterial was considered in homogeneous, isotropic and linear elastic. Discrepancy in biomaterial finite element analysis was unavoidable. Biomaterial as bone and connective tissue were composite material which were complex and sensitive material. Li *et al.*, (2007) reported about material properties of cartilaginous tissue. Different tissue preservation including fresh, frozen and vitrified provided different material properties of the same type of tissue [16]. Smith *et al.*, (2009) estimated material properties of labrum tissue. Two testing including compressive testing and tensile testing provided different material properties [17]. The labrum was cut to eight parts in circumference. Each parts of labrum also given unlike material properties. Several published researches used bony finite element modeling from computerized tomography (CT) scan data, reliability was proved by validation [18-20]. Computerized tomography (CT) scan provided only bony structure. Loads can be transferred not only by bone but also by muscles, ligament or even by prosthesis components

[21]. In this simulation, hip bone had to carry all load without sharing to muscles and ligament that made hip contact force from the simulation higher than the experiment, which some of muscle and ligament covered the hip joint. Biomedical experiment may spend high cost and has limitations. Finite element analysis was useful for prediction and showed visible stress-strain distribution on the bone. Suture of labral repair was a choice in treatment. Suitable treatments were depend on many factor as size and graveness of labral tear, patient's age, clinical characteristics of patient's hip and hip dysplasia.

This study on labral repair can be used as guidance for surgeons to decide which treatment is the most suitable for patients. The limitation of this study was that a pelvis only was compressed by constant load to observe effect from labral repair; but in daily life, hip joints function in multiple forms of activities including sitting, walking and stair-climbing. All activity can affect labral repair and may change resultant. In further studies more condition of activity and material properties would be considered.

6. Conclusion

Finite element analysis was used to evaluate the labral repair effect. The result was shown the labral repaired increased mean equivalent of total strain in labrum tissue but the reducing of labrum thickness did not affect the mean contact force on cartilage and did not effect on bone in overall. The simulation had agreeable result with the experimental testing.

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