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Technic Note

3D Printer Assisted Setup for Acetabular Labrum Biomechanics

Acetabular Labrum Biyomekaniği için 3D Yazıcı Destekli Kurulum

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Abstract: The hip joint is responsible for providing a support of the weight of upper body. It provides a force transmission from the axial skeleton to the lower extremities. Therefore, labral tears might lead to serious outcomes with time; such as hip pain, degeneration, even arthritis. In this study, we aimed to determine human acetabular labrum mechanical properties with the help of a newly designed compression test set-up. Study was performed with 9 human acetabular labrum tissues obtained from volunteers (with the average age of 65,5±8,1; 4 female and 5 male). The samples were evaluated separately by using a 3D printer designed test set-up with a 100% humidity and a displacement rate of 10 mm/min at 24(±1) °C. The data up to 70 N loading were used for biomechanical evaluations. The average elastic modulus (0.022 MPa ± 0.001) was evaluated with the maximum stress (1.169 MPa ± 0.052) and the maximum strain (53.09 ± 2.643) at 70 N loading. In conclusion, the obtained data verifies that the test set-up is like to anatomical design and data is acceptable.
Keywords: 3D printed testing setup, compression test, Acetabular labrum biomechanics

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Özet: Kalça eklemi, üst ekstremitenin ağırlığının desteklenmesinden sorumludur. Eksenel iskeletten alt ekstremitelere kuvvet iletimini sağlar. Bu nedenle, labral yırtıklar zamanla ciddi sonuçlara yol açabilir; kalça ağrısı, dejenerasyon, hatta artrit gibi. Bu çalışmada yeni tasarlanan kompresyon testi düzeneği sayesinde insan asetabular labrumunun mekanik özelliklerinin belirlenmesi amaçlanmıştır. Çalışma, 9 adet gönüllüden (yaş ortalaması 65,5 ± 8,1; 4 kadın ve 5 erkek) elde edilen insan asetabular labrum dokusu ile gerçekleştirilmiştir. Örnekler, % 99 nem koşulu sağlanarak ve 24 (± 1) ° C sıcaklıkta 10 mm / dk yer değiştirme hızı ile 3D yazıcı tasarımlı bir test düzeneği kullanılarak değerlendirilmiştir. Biyomekanik değerlendirmeler için 70 N'ye kadar yüklenme altındaki veriler kullanılmıştır. Ortalama elastik modül değeri (0.022 MPa ± 0.001), maksimum gerilme (1.169 ± 0.052) ve maksimum yer değiştirme (53.09 ± 2.643) değerleri elde edilmiştir. Sonuç olarak, elde edilen veriler test düzeneğinin anatomik yapıya benzediğini ve verilerin kabul edilebilir aralıklarda olduğunu doğrulamaktadır.
Anahtar Kelimeler: 3B basılmış test düzeneği, kompresyon testi, asetabular labrum biyomekaniği

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1. Introduction

The hip joint is responsible for providing a support of the weight of upper body. It provides a force transmission from the axial skeleton to the lower extremities. This structure allows mobility to the body (1). It is a ball-socket type synovial joint that which is settled in between the acetabulum of pelvis and head of femur. The femoral head placed into the acetabular socket and the acetabulum is providing stability of the hip joint (2). The acetabular labrum is a fibrocartilaginous tissue which is attached to the rim of the acetabulum and it continues as the transverse acetabular ligament inferiorly bridging the cotyloid fossa. The acetabular labrum increases the depth, surface area, volume, and stability of the hip joint (3).

Labral tears are the most common cause for intra-articular hip pain in young, non-arthritic patients. However, relation between labral tears and onset of arthritis continues to be unknown (4) (5). The function of the acetabular labrum can be impaired as a result of deterioration caused by hip pathologies such as, femoro-acetabular impingement (FAI) dysplasia and capsular laxity or by acute trauma, degeneration and repetitive extreme ranges of movement (6) (7). The exact role and function of the acetabular labrum remain under debate (8).

While recent studies have clarified its anatomy its true function as well as its biomechanical and kinematic behaviour have lagged behind. Konrath et al. did not find any significant increase in articular pressure after the removal of the labrum and the transverse ligament (9). The loss of labral mechanical support may result in higher forces in the articular cartilage, damaging this tissue. Recently, Safran et al. demonstrated in an in vitro study that the mean strain below the labrum varies during hip motion (8).

An ex vivo anatomical study was conducted to analyse the variations in morphological parameters of the mid- portion of the labrum (length, thickness, shape, deformation) and femoro-labral strains, during hip adduction to abduction movement (10). Ferguson and colleagues demonstrated that the labrum distributes joint forces, stabilizes the hip, and acts as a seal to promote lubrication and preserve cartilage, and with its removal, the articular cartilage layers compress 40% more quickly (11). Other investigators have shown that the labrum contributes to hip stability by increasing acetabular surface area, volume, and stiffness, and by creating a negative intra-articular pressure that results in resistance to displacement (12). To restore these labral functions, three surgical options exist: debridement, repair, and reconstruction (13).

With the present research, we aimed to determine human acetabular labrum mechanical properties with the help of a newly custom-designed compression test set-up. This test set-up is designed with Solidworks (SolidWorks Corporation, Waltham, MA, USA) and produced with the help of 3D printer system.

2. Materials and Methods

Study Design and Sample Preparation

Ethics consent was obtained from our institution. Nine human fresh labrums were used in this study. The samples were obtained from volunteers (4 female, 5 male) with the average age of 65 (±8;). They were washed and freshly frozen in a sterile saline solution. The compression test set-up (Fig.1) was designed by using a Ultimaker 3 Extended (Ultimaker BV, Utrecht, The Netherlands). Fresh-frozen samples were thawed at room temperature. When they defrost, samples were wrapped with a sterile gauze wet with saline. The compression analysis data was obtained at 100% humidity and at 24(±1) °C with an electromagnetic actuator device (5 kN AG-X; Shimadzu, Kyoto, Japan).

Figure 1. Compression testing set-up.

Biomechanical Analysis

Samples were thawed and prepared as explained previously. The compression analysiswere obtained with a 5 kN load cell and displacement rate of 10 mm / min, by using a 3D printed set-up (Figure 2). The force (N) – elongation (mm) values were taken from a TRAPEZIUM X software and processed by Origin 8. The maximum stress (MPa) and strain values at 70 N loading was obtained with these programmes.

Figure 2. Biomechanical analysis of acetabular labrum specimens.

Statistical Analysis

Statistical Package for the Social Sciences (SPSS version 15.0) was used (IBM Corp., Armonk, New York, USA) for conducting statistical analysis in this study.

3. Results

All nine specimens of the acetabular labrum were tested successfully. Each sample was analyzed separately with a displacement rate of 10 mm / min and data up to 70 N loading is given in Table 1. Moreover, maximum stress (MPa) and strain (a.u.) graph is given in Figure3.

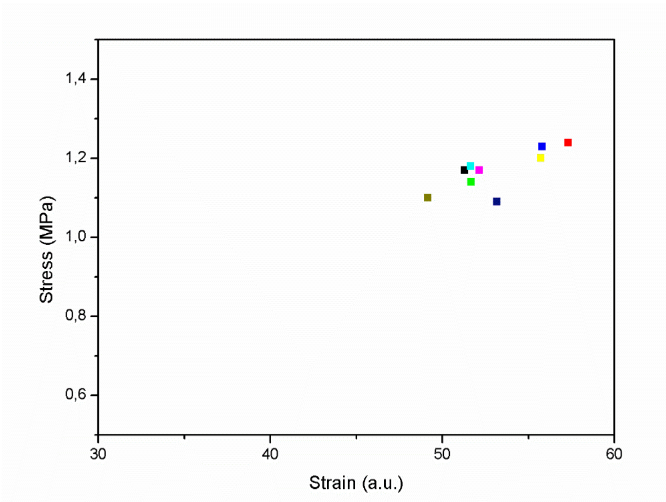

Figure 3. Maximum stress (MPa) and strain (a.u) values after compression analysis.

Table 1. Maximum stress (MPa), maximum strain (a.u.) and elastic modulus (MPa) values at 70 N loading in a compression analysis.

Sample Number	Maximum Stress (MPa)	Maximum Strain (a.u.)	Elastic Modulus (MPa)
1	1.17	51.28	0.023
2	1.24	57.30	0.022
3	1.14	51.65	0.022
4	1.23	55.79	0.022
5	1.18	51.64	0.023
6	1.17	52.14	0.022
7	1.20	55.72	0.021
8	1.10	49.14	0.022
9	1.09	53.15	0.020

The mean elastic modulus (0.021 MPa ± 0.000) was evaluated with the mean maximum stress (1.16 MPa ± 0.05) and the mean maximum strain (53.09 ± 2.64) at 70 N loading.

4. Discussion

This paper has presented the compressive behavior of the human acetabular labrum. The testing was performed on fresh frozen, degenerative samples under physiological conditions. Previous biomechanical trying out of the acetabular labrum typically used a hemipelvis specimen (14), (15) which is hard to position in space due to a confined variety of landmarks. The use of a whole pelvis specimen provided an anterior pelvic plane to position the pelvis, and this plane is likewise used as a reference to position the femur in flexion/extension and abduction/adduction movements. The labrum will increase the articular area by means of 28 % and acetabular quantity via

30 % (16). Acetabular labral tears are as a result of many situations together with trauma (17), instability (13), hip dysplasia (18), iliopsoas impingement (19) and femoro-acetabular impingement that ends in hip or groin pain (5). However the most crucial component of the labral pathology is its affiliation with degenerative trade of the hip (4).

In truth, it's far probably that the initiation of tears is multifactorial and that more than one element desires to be present with the intention to create a tear. Trauma could affect any part of the labrum, however, these results suggest that the anterosuperior quadrant is greater susceptible. Hypolaxity of the anterior pill and the iliofemoral ligament would erupt the tensile loading and in all likelihood shear loading of the anterosuperior labrum. Bony impingement and dysplasia both cause multiplied compressive loading on this portion. Any of those pathologies blended with the reduced biomechanical residences could result in the failure of the labrum in this region.

The acetabular labrum affords a seal towards fluid circulate and out of the significant compartment of the hip (11) (20). This creates hydrostatic strain slowing cartilage consolidation at some stage in the application of a compression load (14). The labral seal additionally produces the "suction effect" resisting distraction of the femoral head from the acetabulum and additionally mechanical aid by using efficaciously deepening the socket. A dilemma of this version is that it does no longer include muscle forces that may apply a compressive load to the hip inside the in vivo situation. In addition the addition of muscle forces might serve to lessen the displacements in all two hip states, intact and labral resection, it is uncertain that whether or not the muscle forces could increase sufficiently to catch up on the good-sized loss of help furnished by means of the labrum in the occasion of injury. On the other hand, in our study, the femoral head was examined anatomically on a single axis. Forces acting on the acetabular labrum should also be examined at flexion / extension, abduction / adduction angles.

5. Conclusion

In conclusion, the test set-up is like to anatomical design of acetabular labrum and it is related to previous studies in the literature. Therefore, we might conclude that the design can be used for further studies. The obtained data is consistent with the biomechanical properties of the human acetabular labrum. The results produced to suggest that the biomechanical properties in the total labral contact may be a contributing factor to the initiation of labrum biomechanics.

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