Complicated superior labral injury concentrates joint loading stress independently of bone morphology in developmental dysplasia of the hip: A Multimodality Imaging Study

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INTRODUCTION:

Developmental dysplasia of the hip (DDH) is a major cause of secondary osteoarthritis. Labral tears are frequently observed in patients with DDH and are considered a potential risk factor for the progression of osteoarthritis. However, it remains unclear whether labral tears occur as a consequence of abnormal mechanical stress caused by morphological deformities, or whether the tears themselves exacerbate abnormal stress regardless of bone morphology. Moreover, although the acetabular labrum extends nearly circumferentially around the acetabulum, the influence of injury location on the joint loading environment has not been elucidated. In this study, we used radial magnetic resonance imaging (MRI) [1], which provides a circumferential assessment of the acetabular labrum, to investigate the impact of labral injury location, and to quantitatively compare the theoretical load distribution predicted from structural morphology using finite element analysis (FEA) with the actual cumulative loading pattern derived from subchondral bone density using computed tomography osteoabsorptiometry (CT-OAM) [2,3]. We hypothesized that 1) the location and severity of labral tears influence the distribution of joint loading stress, and 2) the relationship between labral tears and bony morphology differs by location. The objective of this study was to investigate the associations among labral tear characteristics, acetabular morphology, and stress distribution within the hip joint using a multimodality imaging approach.

METHODS:

45 female patients (54 hips; mean age 30.3 years; 95%CI, 27.0 – 33.6) who underwent periacetabular osteotomy, a type of joint preservation surgery for DDH, at our institution between 2016 and 2024 were included. Preoperatively, radiographic parameters were measured on radiographs, and labral injury was assessed on MRI. Labral abnormalities were assessed in three distinct regions (anterior, superior and posterior) (Figure1A). Labral lesions were categorized into three groups: normal, simple injuries, and complicated injuries (Figure1B). The subchondral bone mineral density of the joint was assessed preoperatively using the CT-OAM. The percentage of the top 20% of areas (HDA) with the highest bone mineral density in each of the three regions was calculated as a percentage of the total area (Figure 2A). Three-dimensional finite element hip models were generated from CT data using Mechanical Finder software. Nonlinear contact analysis under a single-leg stance condition was performed to calculate acetabular cartilage contact area and maximum contact pressure (Figure 2B). In statistical analysis, a multiple linear regression analysis was conducted to identify the factors influencing in HDA percentage. Unpaired t-tests were used to compare patient demographics, radiological evaluations, FEM evaluations and HDA percentage in the simple and complicated groups. Statistical significance was set at $P < 0.05$.

RESULTS:

Multiple regression analyses identified factors influencing HDA percentage (Table 1). A significant correlation was found between the superior HDA percentage and the independent variables. Complicated labral injury in the superior region was identified as a positive influencing factor for the superior HDA percentage (Estimate = 20.5, 95% CI: 4.4 – 36.6, p = 0.013). On the other hand, the anterior and posterior HDA percentage did not show a significant correlation with the independent variable. To investigate the characteristics of labral injuries at each site and their impact on joint mechanics, simple and complicated injury groups for each region were compared. For anterior labral injuries, no significant differences were observed in the patient demographics, radiological evaluations, or HDA percentage distribution between the two groups. Regarding superior labral injuries, there were no differences in femoral head coverage parameters, such as the center-edge angle and the acetabular head index between two groups. Additionally, the anterior HDA percentage was significantly lower (simple injury vs complicated injury, 16.5 [95% CI:13.0 – 20.1] vs 6.9 [95% CI: 0.1 – 13.6] , p = 0.005), whereas the superior HDA percentage was significantly higher in the complicated injury group than in the simple injury group(simple injury vs complicated injury, 65.1 [95% CI: 58.5 – 71.7] vs 82.1 [95% CI: 72.7 – 91.5] , p = 0.003). For posterior labral injuries, no significant differences in the radiological scores were found between the two groups. In FEA, anterior complicated injury group exhibited a higher maximum contact pressure than the simple injury group (simple injury vs complicated injury, 5.2 [95% CI: 3.3-72] vs 6.2 [95% CI: 2.8-9.5], p=0.005), whereas no significant differences were observed between the two groups in the superior or posterior region.

DISCUSSION:

In the superior region, the complicated injured group had a significantly lower anterior HDA percentage and a significantly higher superior HDA percentage compared with the simple injured group. However, FEA showed no relationship with bony morphology. These results suggest that femoral head instability caused by labral tears, rather than the influence of bone morphology, may be the primary factor of loading stress concentration in the superior region. The stress abnormality in the complicated injury group is consistent with previous cadaveric studies showing that multidirectional labral tears increase femoral head instability [4]. Interestingly, a significant difference in stress distribution was observed only in the superior region, whereas no difference was found in the anterior region regardless of the extent of labral damage. This may suggest that anterior femoral head instability is inherently present in DDH, even before labral damage occurs. In conclusion, this study suggests that labral tear–morphology relationships vary by location, with no link between severity and morphology in the superior region, and joint loading stress distribution–labral injury associations differ by both location and severity.

SIGNIFICANCE/CLINICAL RELEVANCE: Complicated superior labral tears increase joint loading stress regardless of bone morphology, underscoring the need for location-specific strategies in joint preservation for DDH.

REFERNCES: [1] Cloos MA, et al. J Magn Reson Imaging. 2019 [2] Keyak JH, et al. J Biomed Mater Res. 1994 [3] Muller-Gerbl M, et al. Skeletal Radiol 1989 [4] Fithian AT, et al. J Sports Med. 2024

IMAGES AND TABLES:

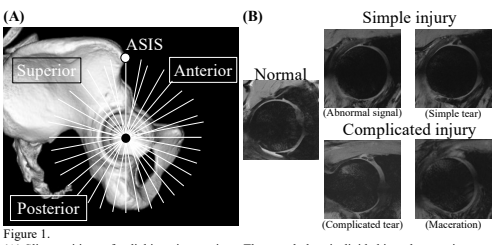

Figure 1.
(A) Slice positions of radial imaging sections. The acetabulum is divided into three regions.
(B) Representative case images of acetabular labral injuries.
ASIS; anterosuperior iliac spine

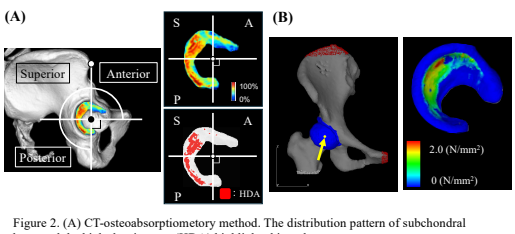

Figure 2. (A) CT-osteoabsorptiometry method. The distribution pattern of subchondral bone and the high-density area (HDA) highlighted in red.
(B) Three-dimensional finite element model. Representative image of distribution of the joint contact pressure on the acetabular cartilage of the hip.

Table 1. Multiple liner regression to predict factors associated with superior HDA percentage.

Dependent variable: **Superior HDA percentage** (R^2=0.21, F (6,51) =2.3, p = 0.044)

Independent variable	Estimate	95% CI	T value	P value
Intercept	80.3	35.4 – 125.1	3.6	<0.001
CE angle	-0.0	-0.5 – 0.4	0.2	0.803
ARO	-0.0	-0.9 – 0.4	0.1	0.846
AHI	-0.2	-0.7 – 0.3	0.8	0.401
Anterior labral complicated injury	-0.6	-11.2 – 9.9	0.1	0.898
Superior labral complicated injury	**20.5**	**4.4 – 36.6**	**2.5**	**0.013**
Posterior labral complicated injury	-2.1	-21.3 – 17.1	0.2	0.825

HDA percentage; The percentage of the top 20% of areas with the highest bone mineral density