Intercondylar Notch Stenosis of Knee Osteoarthritis and Relationship between Stenosis and Osteoarthritis Complicated with Anterior Cruciate Ligament Injury

A Study in MRI

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Abstract: The aim of this study was to research whether the patients with knee osteoarthritis (OA) exist intercondylar notch stenosis and the relationship between stenosis and OA complicated with anterior cruciate ligament (ACL) injury from magnetic resonance imaging (MRI).

A total of 79 cases of moderate–severe OA patients and 71 cases of healthy people were collected; among these OA patients, 38 were OA complicated with ACL injury and 41 were simple OA. The intercondylar notch was divided into A, U, and W types according to the notch shape in the axial sequence of MRI. Measurement of the notch width index (NWI) in the sequences of axial (NWI-1), coronal (NWI-2), and ACL attachment point at femoral (NWI-A) was done. The differences of NWI in different groups and different sequences were compared and the NWI cut-off values in different sequences were resolved by a receiver operating characteristic (ROC) curve which could be used as indicators for intercondylar notch narrowing were calculated.

The proportion of type A in moderate–severe OA group was larger than healthy group, and similar to OA complicated with ACL injury and simple OA groups (P < 0.05). The NWI values of the moderate–severe OA group in three sequences were smaller than the healthy group, and similar to OA complicated with ACL injury and simple OA groups (P < 0.001). The cut-off values of ROC curve were NWI-1 < 0.266, NWI-2 < 0.247, and NWI-A < 0.253 in the moderate–severe OA group, and NWI-1 < 0.263, NWI-2 < 0.246, and NWI-A < 0.253 in the OA complicated with ACL injury group. The intercondylar notch of moderate–severe OA patients exist significant stenosis. Type A is one of the variables that predispose a notch to stenosis. Intercondylar notch stenosis and type A are risk factors for moderate–severe OA patients complicated with ACL injury.

Abbreviations: ACL = anterior cruciate ligament, CI = confidence interval, MRI = magnetic resonance imaging, NWI = notch width index, OA = osteoarthritis, OR = odds ratio, ROC = receiver operating characteristic, SD = standard deviation.

INTRODUCTION

Knee osteoarthritis (OA) is characterized by the destruction of articular cartilage and osteophyte formation, resulting in joint space narrowing. The incidence is higher in the elderly, especially in women. Knee OA can cause severe joint pains and lead to disability at last. The existence of osteophyte will increase the risk of the complication of anterior cruciate ligament (ACL) injury. There are not any sound clinical treatments against OA, the common method to cure severe OA patients is knee replacement surgery. In view of the serious consequences and expensive treatment cost of OA, the prevention of high-risk population is essential and crucial.

Studies show that, the osteophyte of OA patients will lead to intercondylar notch stenosis.1,2 Anderson et al3 and Souryal et al4 put forward the concept of notch width index (NWI) successively, so as to evaluate the intercondylar notch stenosis. NWI equals intercondylar notch width divided by femoral condyles width. It is a relative index, which can reduce measurement error, balance individual difference, and reflect the size of intercondylar notch more accurately. Both x-ray and CT (computed tomography) images can calculate NWI; however, the images can’t see the soft tissue such as ligament and they may exist overlapping,5 so the error is high. Fortunately, there are no such problems in MR (magnetic resonance) images, so we choose MR images in this study. Many scholars have studied the magnetic resonance imaging (MRI) images of intercondylar notch, they choose the sequence of axial,6 coronal,7 and the ACL attachment point at femoral,8 and the intercondylar notch shape type into A, U, and W typing.9 In this study, moderate–severe OA patients were selected as the main research object and these OA patients were divided into two groups based on complication with ACL injury. Different sequences of NWI in MRI were compared in different groups to determine the relationship between intercondylar notch stenosis and OA complicated with ACL injury.
MATERIALS AND METHODS

Research Object

A retrospective case-control study was conducted in Lanzhou University Second Hospital (Lanzhou, China) during January 2011 to June 2015. Inclusion criteria: (1) middle-aged and old people (≥45 years old). (2) The diagnosis was OA according to the American Rheumatism Association knee OA diagnostic criteria, furthermore we choose moderate–severe OA patients whose K-L score was grade II, III, IV in MRI and the severity index of KOA (ISOA) score was >4. (3) No clear knee joint injury or operation history. (4) MRI images are clear and sequences are complete. (5) OA is the first occurrence of the disease. Exclusion criteria: (1) <45 years old. (2) The diagnosis was not clear or mild OA whose K-L score was I or ISOA score was no >4. (3) The ACL injury occurred before the OA. Out of an initial cohort of 1107 MRI, we selected 150 cases, 79 patients and 71 controls. All of the patients gave informed consent; the study was conducted under the supervision of the Ethics Committee of Lanzhou University Second Hospital.

Measurement Methods

Using the Phillips 3.0-T MRI scanner, patients were placed in a supine position, knee flexion 10°–15°, with the center of the coil located at the lower pole of the patella. Scan sequence: proton fast spin echo with fat saturation (PD-TSE-FS-TRA) in axial, TR 2886 ms, TE 25 ms, 160 mm FOV, layer thickness 3 mm. SE-T1WI sequence in coronal, TR 520 ms, TE 20 ms, FOV 160 mm, layer thickness 3 mm. The sequence was selected which showed intercondylar notch clearly and was consistent with the measurement position. RadiAnt DICOM Viewer 1.9 software was used to measure. The classification of the intercondylar notch shape in axial is divided into three types: A, U, and W refers to Al-Saeed et al9 (Figure 1A–C). Measurement of NWI-1 in axial refers to Stein et al6 (Figure 1 D), NWI-2 in coronal refers to Domzalski et al7 (Figure 1E), and NWI-A in ACL attachment point at femoral refers to Hoteya et al8 (Figure 1F). The measurement was completed by three people independently; the final data was the average value, negotiation when the shape type is different.

Statistical Analysis

Data were analyzed by SPSS 22.0 software; results were displayed in the form of X ± SD. Comparison of different levels of NWI among different groups was done by one-way ANOVA; comparison of rates were done by the chi-square test. Two parameters correlation test were done by the Spearman test. P <0.05 was seen as statistically significant.

RESULTS

General Information

As shown in Tables 1 and 2, there were 71 cases in the healthy group and 79 cases in the moderate–severe OA group. Divided these OA patients into two groups based on whether complicated with ACL injury. There were 41 cases in the simple

FIGURE 1. Intercondylar notch shape typing on an axial image and the measurement of different levels of NWI. (A) Type A: the tip of the notch is small and pointed, like the letter “A.” (B) Type U: the tip of the notch is large and dull, like the reverse letter “U.” (C) Type W: two tops; there are two tip edges which are large in shape, like the reverse letter “W.” (D) Measurement of NWI-1 on an axial image. The image is most clear in axial sequence, the baseline is the tangent of cartilage at internal and external condyle of femur, notch depth (D) is the distance between the tip of the notch and the baseline, condylar width (W) is the length of a line which passes the popliteal groove in the lateral femoral condyle and parallel to the baseline, notch width (N) is the length of a line which is at the upper 2/3 of D parallel to the baseline. (E) Measurement of NWI-2 on a coronal image. The image which we choose can show two cruciate ligaments and condyle ridge. Baseline and W are similar to (D), N is the notch width on W. (F) Measurement of NWI-2 on ACL attachment point at femoral. The image we choose can show two cruciate ligaments and the ACL attachment point at femoral. W is the length of a line which passes the exit of lateral femoral condyle and is parallel to the baseline, N is the notch width on W. ACL = anterior cruciate ligament, NWI = notch width index, NWI-1 = notch width index in the sequences of axial, NWI-2 = notch width index in the sequences of coronal.
TABLE 1. Gender and Age (Year) in Healthy Group and OA Group

|        | Healthy Group |         | OA Group |         | Total | Statistic |
|--------|---------------|---------|----------|---------|-------|-----------|
| Cases  | Age           |         | Cases    | Age     |       |           |
| Male   | 33            | 53.42 ± 6.50 | 27       | 56.44 ± 8.41 | 60    |           |
| Female | 38            | 52.32 ± 6.18 | 52       | 57.44 ± 8.92 | 90    |           |
| Total  | 71            | 52.83 ± 6.31 | 79       | 57.10 ± 8.71 | 150   |           |

OA = osteoarthritis.

TABLE 2. Gender and Age (Year) in Simple OA Group and OA + ACL Injury Group

|        | Simple OA Group |         | OA + ACL Injury Group |         | Total | Statistic |
|--------|-----------------|---------|-----------------------|---------|-------|-----------|
| Cases  | Age             |         | Cases                | Age     |       |           |
| Male   | 17              | 55.12 ± 8.71 | 10       | 58.70 ± 7.78 | 27    |           |
| Female | 24              | 57.79 ± 9.26 | 28       | 57.14 ± 8.78 | 52    |           |
| Total  | 41              | 56.68 ± 9.03 | 38       | 57.55 ± 8.45 | 79    |           |

ACL = anterior cruciate ligament, OA = osteoarthritis.

OA group, 38 cases in the OA complicated with ACL injury group.

Comparison of Intercondylar Notch Shape Type Between Different Groups

As shown in Table 3, there were only 2 cases in the healthy group and 1 case in the moderate–severe OA group about type W. Because the cases in type W were very less, and the notch width was close to type U, so type W was merged into type U. Type A in the OA group accounted for 75.9%, significantly >57.7% in the healthy group. The result of chi-square test was \( \chi^2 = 5.633, P = 0.018, P < 0.05 \), means that the shape type between the two groups was statistically different. Type A was more and type U was less in the OA group compared with simple OA group. The proportion of type A was 2.311 times than that of type U.

As shown in Table 4, only 1 case was in the simple OA group and none in the OA complicated with ACL injury group about type W. Merge type W into type U. The proportion of type A in simple OA group was significantly higher than that of the OA complicates with ACL injury group. The result of the chi-square test was \( \chi^2 = 4.756, P = 0.029, P < 0.05 \), means that the probability of OA patients complicated with ACL injury in type A was 3.422 times than that of type U.

Comparison of Notch Types Between OA + ACL Injury Group and Simple OA Group

|        | OA Group | Total | Statistic |
|--------|----------|-------|-----------|
| A      | 60* (75.9%) | 101   | \( \chi^2 = 5.633 \) |
| U      | 19* (24.1%) | 49    | \( P = 0.018 \) |
| Total  | 79 (100%)  | 150   | OR = 2.311 |

OA = osteoarthritis, OR = odd ratio.

Comparison of Notch Types Between OA Group and Healthy Group

|        | Healthy Group | OA Group | Total | Statistic |
|--------|---------------|----------|-------|-----------|
| A      | 41 (57.7%)    | 60* (75.9%) | 101   | \( \chi^2 = 5.633 \) |
| U      | 30 (42.3%)    | 19* (24.1%) | 49    | \( P = 0.018 \) |
| Total  | 71 (100%)     | 79 (100%)  | 150   | OR = 2.311 |

OA = osteoarthritis, OR = odd ratio.

*OA group compared with healthy group \( P < 0.05 \).

Comparison of NWI in Different Sequences Between Different Groups

As shown in Table 5, the cut-off values of NWI-1 in axial, NWI-2 in coronal, and NWI-A in ACL attachment point at femoral were smaller in the OA group than the healthy group. The one-way ANOVA result were \( P < 0.001 \), which means the differences about NWI between the two groups were statistically significant (\( F = 10.549/14.456/12.027, P < 0.001 \)).

As shown in Table 5, the cut-off values of NWI-1 in axial, NWI-2 in coronal, and NWI-A in ACL attachment point at femoral were smaller in the OA complicated with ACL injury group than the simple OA group. The one-way ANOVA result is \( P < 0.001 \), which means the probability of occurrence of OA patients complicated with ACL injury about NWI between the two groups were statistically significant (\( F = 25.216/14.963/23.855, P < 0.001 \)).

Correlation Test

The correlation between NWI and whether suffering from OA in healthy and OA groups was tested. As whether suffering from disease was a binary data, NWI was a measurement data, so we used the Spearman test. The correlation coefficient and \( P \) values of NWI-1, NWI-2, and NWI-A were \( r = -0.212/-0.209/-0.232, P = 0.009/0.010/0.004 \), respectively. \( P < 0.01 \), therefore there was a significant correlation between whether suffering from moderate–severe OA, and NWI-1, NWI-2, and NWI-A in different sequences.

The correlation between NWI and whether complicated with ACL injury in OA patients was tested. The correlation coefficient and the \( P \) values of NWI-1, NWI-2, and NWI-A were \( r = -0.503/-0.338/-0.484, P < 0.001 \). Therefore, there was an extremely significant correlation between whether complicated with ACL injury in OA patients, and NWI-1, NWI-2, and NWI-A in different sequences.

Receiver Operating Characteristic Curve

Figure 2 shows the receiver operating characteristic (ROC) curve of the NWI-1, NWI-2, and NWI-A of different sequences.
in OA and healthy patients. The area under curve (AUC) values were, respectively, \( A = 0.622/0.621/0.634 \), \( P = 0.010/0.011/0.005 \); among them the AUC of NWI-A was the largest. The best cut-off value of ROC curve is corresponding to the maximum value of Youden index (sensitivity + specificity – 1). So the cut-off values of NWI-1, NWI-2, and NWI-A were 0.266/0.247/0.253, respectively. The cut-off values of NWI were <95% confidence interval (CI) of healthy group in the corresponding sequence, and the AUC were >0.5; \( P \) value was <0.01, so the cut-off values were reasonable. Therefore, NWI-1 <0.266, NWI-2 <0.247, and NWI-A <0.253 can be considered as intercondylar notch stenosis and risk factors of suffering from OA.

Figure 3 shows the ROC curve of the NWI-1, NWI-2, NWI-A of different sequences in OA patients. The AUC were, respectively, \( A = 0.791/0.724/0.780 \), \( P \leq 0.001 \); among them the AUC of NWI-1 was the largest. The best cut-off values of NWI-1, NWI-2, and NWI-A were 0.263/0.246/0.253, respectively. The cut-off values of NWI were <95% CI of simple OA group in the corresponding sequence, and the AUC were >0.5; \( P \) value was <0.01, so the cut-off values were reasonable. Therefore, NWI-1 <0.263, NWI-2 <0.246, and NWI-A <0.253 can be considered as risk factors for OA patients complicated with ACL injury.

**DISCUSSION**

Many scholars have studied the intercondylar notch of OA patients. Shepstone et al\(^4\) found that the differences between healthy and OA patients are related mostly to the shape of the medial condyle edge: in the nonosteoarthritic group it tends to exhibit a concavity and in the osteoarthritic group it tends to be concave.

**TABLE 5.** Comparison of Different Sequences of NWI Between OA Group and Healthy Group

|          | Healthy Group |          | OA Group |          | Statistic |
|----------|---------------|----------|----------|----------|-----------|
|          | \( \overline{X} \pm SD \) | 95%CI     | \( \overline{X} \pm SD \) | 95%CI     |           |
| NWI-1    | 0.272 ± 0.017 | (0.268,0.276) | 0.265 ± 0.012\(^*\) | (0.262,0.267) | \( F = 10.549, P = 0.001 \) |
| NWI-2    | 0.254 ± 0.017 | (0.250,0.258) | 0.244 ± 0.016\(^*\) | (0.240,0.247) | \( F = 14.456, P < 0.001 \) |
| NWI-A    | 0.262 ± 0.023 | (0.256,0.267) | 0.250 ± 0.019\(^*\) | (0.245,0.254) | \( F = 12.072, P = 0.001 \) |

**TABLE 6.** Comparison of Different Sequences of NWI Between OA + ACL Injury Group and Simple OA Group

|          | Simple OA Group |          | OA + ACL Injury Group |          | Statistic |
|----------|-----------------|----------|-----------------------|----------|-----------|
|          | \( \overline{X} \pm SD \) | 95%CI     | \( \overline{X} \pm SD \) | 95%CI     |           |
| NWI-1    | 0.270 ± 0.010  | (0.267,0.274) | 0.258 ± 0.011\(^*\) | (0.255,0.262) | \( F = 25.216, P < 0.001 \) |
| NWI-2    | 0.250 ± 0.012  | (0.246,0.254) | 0.237 ± 0.018\(^*\) | (0.231,0.243) | \( F = 14.963, P < 0.001 \) |
| NWI-A    | 0.259 ± 0.015  | (0.254,0.263) | 0.240 ± 0.019\(^*\) | (0.234,0.246) | \( F = 23.855, P < 0.001 \) |

ACL = anterior cruciate ligament, CI = confidence interval, NWI-1 = notch width index in the sequences of axial, NWI-2 = notch width index in the sequences of coronal, NWI-A = notch width index in the ACL attachment point at femoral, OA = osteoarthritis, SD = standard deviation.

\(^*\)OA group compared with healthy group \( P \leq 0.001 \).

ACL = anterior cruciate ligament, CI = confidence interval, NWI-1 = notch width index in the sequences of axial, NWI-2 = notch width index in the sequences of coronal, NWI-A = notch width index in ACL attachment point at femoral, OA = osteoarthritis, SD = standard deviation.

\(^*\)OA complicated with ACL injury group compared with simple OA group \( P < 0.001 \).

FIGURE 2. ROC curves of different sequences in OA and healthy groups. OA = osteoarthritis, ROC = receiver operating characteristic.
straight. This difference in shape may reduce the width of the notch; the morphology of OA patients may be the response to altered biomechanics. Wada et al through anatomic measurement of intercondylar notch in OA patients found that osteophyte growth seems to correlate with the progression of OA, which will narrow the intercondylar notch and reduce the NWI. León et al used arthroscope and examined 69 knees with degenerative knee arthritis but without ACL laxity; he found that there may appear four types of hyperplasia in intercondylar notch, among these the hyperplasia in top and opening was the most common type; the hyperplasia is responsible for the reduction in intercondylar notch width and decreases the NWI and leads to intercondylar notch narrowing. In this study, we found that the cut-off values of NWI-1, NWI-2, and NWI-A in moderate–severe OA patients were significantly less than those of healthy persons ($P < 0.01$), which showed that there was a significant intercondylar notch stenosis in moderate–severe OA patients, these were consistent with the conclusions of the above-mentioned scholars.

In the studies of intercondylar notch shape, most scholars divided it into three types of A, U, and W. Anderson et al in the study of CT images found that the shape of the notch in type U was not easy to be narrow. Van Eck et al in the study of arthroscopic found that the width of the intercondylar notch in type A was smaller than that of type U. In a study Sutton et al showed that the shape of notch was related to gender; the proportion of type A in female was larger than male, and the notch width was smaller than that of male, which means that type A shape of intercondylar notch is easy to narrow. In the study of MRI, Al-Saeed et al found that the notch width of type A was smaller than other types and the shape of the notch was a risk factor for ACL injury, and the type A patients were easier to suffer from ACL injury. In this study, we found that the proportion of type A in moderate–severe OA patients was higher than that of healthy people. As well as the proportion of type A, OA complicated with ACL injury patients was significantly higher than that of simple OA patients. These two points indicate that type A shape was easy to cause intercondylar notch stenosis.

Many scholars have measured NWI by imageology. However, both x-ray and CT images have overlapped picture and are influenced by the photograph position heavily, so the error is large. MRI don't have ghosting, and can display the soft tissue such as joint ligaments clearly, so the error is negligible.

Therefore, there were many studies of intercondylar notch on MRI, but no clear NWI cut-off value of intercondylar notch stenosis was made. Al-Saeed et al measured NWI on MRI of 560 cases at the depth of 1/2 in the axial sequence; they considered NWI $>0.270$ was normal and NWI $<0.269$ was intercondylar notch stenosis; but in this article, the authors didn’t propose the method for formulating the cut-off value. Stein et al used measured axial NWI at the depth of 2/3 on MRI of 160 patients with knee OA, the result was that the NWI of simple OA patients was $0.263 \pm 0.03$, OA complicated with ACL injury was $0.246 \pm 0.03$, and they took NWI $<0.2$ as the index intercondylar notch stenosis. But the proportion whose NWI $<0.2$ was just $0.7\%$ in simple OA patients, and in OA complicated with ACL injury patients the proportion was just $4.4\%$, so we believe that the cut-off value was not reasonable. Sonnery-Cottet et al measured the NWI of coronal sequence; the NWI in healthy group was $0.27 \pm 0.02$, in ACL injury group was $0.22 \pm 0.02$, and they considered that NWI $<0.21$ was a risk factor for ACL injury. Park et al obtained that the NWI of healthy women in MRI coronal sequence was $0.25 \pm 0.02$. Domzalski et al measured 76 cases of juveniles on MRI coronal sequence; they got NWI of coronal sequence; the NWI in healthy group was $0.273 \pm 0.033$, their conclusion is that NWI $<0.25$ can be considered as intercondylar notch stenosis. There is no ACL existing in the level of P, so the guidance of ACL injury maybe little, but the other three levels exist in ACL, so we choose axial, coronal, ACL attachment point at femoral (A) and an image after ACL attachment point (P), in healthy people NWI-A $= 0.266 \pm 0.030$ and NWI-P $= 0.273 \pm 0.033$. Their conclusion is that NWI $<0.25$ can be considered as intercondylar notch stenosis. Therefore, NWI in different sequences of moderate–severe OA group was smaller than the healthy group, and it was a statistical difference. So we considered that moderate–severe OA patients had obviously intercondylar notch stenosis. Meanwhile, NWI in different sequences of OA complicated with ACL injury group was smaller than simple OA group also with statistical difference. This means that the intercondylar notch of OA complicated with ACL injury patients was more stenosis than simple OA patients; intercondylar notch stenosis was a risk factor for OA patients complicated with ACL injury. We obtained cut-off values of NWI in different sequences of the moderate–severe OA group and OA complicated with ACL injury groups.
Everhart et al25 found that in the knee joint movement, ACL can poor and easy to injury in intercondylar notch stenosis patients. The reason of ACL injury caused by the intercondylar notch stenosis is variable. Stijak et al23 and Dienst et al24, as per their research work, think that the ACL’s cross-sectional area was small, strength was weak, biological performance was poor and easy to injury in intercondylar notch stenosis patients. Everhart et al25 found that in the knee joint movement, ACL can collide with the stenotic intercondylar notch, resulting to wear and tear and finally lead to ACL injury. León et al25 found that OA patients can appear with various types of osteophytes and different intercondylar fossa impingement. When the osteophyte is in notch outlet which can lead to impingement of middle ACL and when the osteophyte is on top of notch outlet, it can lead to impingement of middle and front ACL, Grade IV OA with severe intercondylar notch stenosis, most parts of the notch have osteophyte, can lead to extrusion and deformation of large part of ACL. This intercondylar notch impingement syndrome described previously can lead to ACL injury. Comerford et al26 found the phenomenon that the dog with narrow intercondylar notch had a high risk of ACL injury. Molecular biology research found that narrow intercondylar fossa could wear ACL, increase the activity of matrix metalloproteinase (MMP) activity, the deposition of sulfated glycosaminoglycan (GAG), and the remodeling of collagen in wear areas, and then cause irreversible damage to ACL. Hernigou et al27 studied x-ray and CT images of 30 cases of OA patients, they discovered that in OA complicated with ACL injury group according to ROC curve, which can be used as indicators to determine the stenosis of the intercondylar notch. A number of studies have confirmed that intercondylar notch stenosis is an independent risk factor for ACL injury, and the cut-off value of NWI of stenosis patients is smaller than the healthy people.5,18–22 Patients with left and right bilateral ACL injuries have cut-off value of NWI smaller than unilateral injury patients.2,3 The reason of ACL injury caused by the intercondylar notch stenosis is variable. Stijak et al23 and Dienst et al24, as per their research work, think that the ACL’s cross-sectional area was small, strength was weak, biological performance was poor and easy to injury in intercondylar notch stenosis patients.

CONCLUSIONS

In summary, moderate–severe OA patients exist intercondylar notch stenosis, and the A type of intercondylar notch shape was more likely to be narrow. Meanwhile, the occurrence of OA patients complicated with ACL injury was positively related to the intercondylar notch stenosis. In OA complicated with ACL injury patients the width of the intercondylar notch was smaller and the proportion of type A was larger than simple OA patients. Intercondylar notch stenosis is a risk factor for OA patients complicated with ACL injury. Measurement of different levels of NWI was helpful for the judgment of intercondylar notch stenosis, providing timely prevention measures for OA patients that could reduce the incidence of ACL injury complication.

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