

## Article

# Applicability of Semi-Quantitative Evaluation of the Intercondylar Notch

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## Featured Application: Semi-quantitative evaluation of the intercondylar notch in MRI.

**Abstract:** The intercondylar notch (IN) can differ in morphology and size, influencing the contained ligaments. For a better understanding of the influence of the IN's anatomy on knee pathologies, a classification of different shapes was proposed. However, a detailed evaluation of the reliability of these classifications is lacking thus far. In coronal knee MRIs of 330 patients, the IN width was measured and three shapes were calculated to generate objective control results. Notch shapes were classified by two blinded investigators, first without and then with visual assistance to guide the shape classification. The distribution of the three different shapes was as follows: A-shape: n = 43, 13.0%; inverse U-shape: n = 100, 30.3%;  $\Omega$ -shape: n = 183, 56.7%. The semi-quantitative evaluation distribution was as follows: A-shape: n = 44, 13.3%; inverse U-shape: n = 37, 11.2%;  $\Omega$ -shape: n = 249, 75%; there was fair ( $\kappa = 0.35$ ) agreement compared to that of the control results. The assisted semi-quantitative evaluation distribution was as follows: A-shape: n = 44, 13.3%; inverse U-shape: 103, 31.2%;  $\Omega$ -shape: n = 183, 55.3%; there was very good ( $\kappa = 0.92$ ) agreement compared to that of the control results. In the shape evaluation of the IN, rigid guidelines and visual assistance must be used to ensure reliability. The utilization of visual assistance led to higher inter- and intra-rater agreements in the semi-quantitatively evaluation of the IN shape when compared to those in the classification without visual assistance.

**Keywords:** MRI; knee joint; intercondylar notch; intercondylar space; semi-quantitative evaluation



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## 1. Introduction

The intercondylar notch (IN) has been widely investigated in the literature, as it is an important morphological structure in the knee joint that houses some of its major stabilizing structures (anterior and posterior cruciate ligaments (ACLs and PCLs, respectively), meniscal roots and menisiofemoral ligaments (MFLs)). Therefore, changes to this osseous structure influence these structures within [1–11]. The term intercondylar space was defined to reflect this intimate relationship [12].

Changes in the IN have been associated with ruptures and degeneration in the ACL, which highlights the importance of the definition of cut-off values for the width of the IN (notch width, NW) for risk evaluation. For the same reason, the notch width index (NWI) was defined as a ratio between the NW and bicondylar width [13]. Here, however, discussion arose on the accuracy of these measurements and the index for risk assessment in clinical practice [14].

For easier evaluation of the morphology of the IN, different shapes were defined (A-shape, U-shape, W-shape and wave-like shape), and a correlation was found between narrower notches and ACL injury, post-injury outcomes and surgical or conservative treatment [14–18]. Additionally, the IN is not a static formation, with the shape and

width changing throughout life, from a wider A-shape to a narrower  $\Omega$ -shape with the development of ridges at the osteochondral border [12,19,20].

Until now, these previously described shapes have not been tested for their reliability, reproducibility and applicability in clinical praxis. Only one of these classification systems is based on and defined by specific measurements, and, therefore, a control for the distribution of shapes may be available. Thus, the aim of this study was to test the classification system of Hirtler et al. [12] for its applicability and reproducibility in clinical routine. Our hypothesis was that semi-quantitative evaluations (the combination of shape evaluation and measurements of the NW) are reliable and comparable with the calculated classification.

## 2. Materials and Methods

### 2.1. Study Design and Patient Cohort

This study was designed as a retrospective cross-sectional evaluation, and approval from the institutional review board was obtained (blinded for review). From the consecutive MRIs performed (blinded for review;  $n = 1180$ ) using a single device (Philips Achieva<sup>®</sup> 3.0 T combined with a standard Philips Sense<sup>®</sup> knee coil 8 elements, Philips Healthcare, DA Best, Eindhoven, The Netherlands), a total of 330 patients of different ages, with a maximum of 60 subjects per predefined age group (<11 years, 11–20 years, 21–30 years, 31–45 years, 46–60 years and >60 years), were selected. The age groups were predefined based on the completion of ossification [12,21–23] and the prevalence of degenerative joint disease [12,24–26].

Subjects with injuries to the cruciate ligaments, fractures to the distal femur or proximal tibia, surgeries in the area of the knee joint, tumors, moderate to severe osteoarthritis (Kellgren and Lawrence grade 3 to 4, radiological criteria were applied accordingly) or insufficient image quality were excluded.

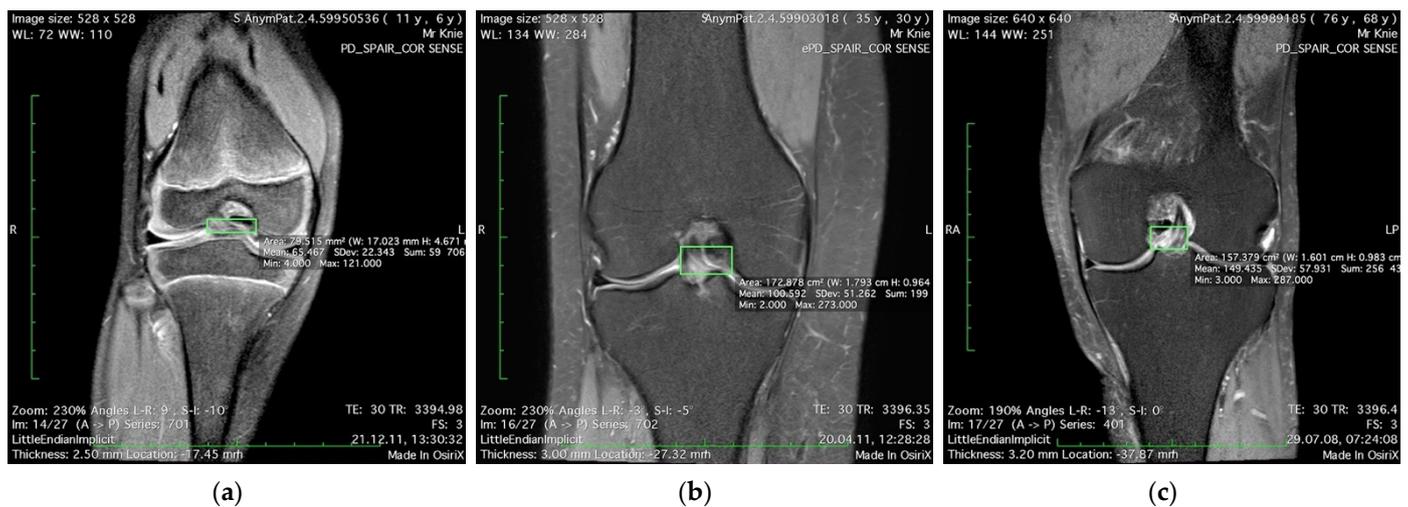
The final cohort was composed of 36 patients (20 male and 16 female) in the group younger than 11 years, 56 patients (26 male and 30 female) in the group between 11 and 20 years, 60 patients (31 male and 29 female) in the group between 21 and 30 years, 60 patients (31 male and 29 female) in the group between 31 and 45 years, 58 patients (28 male and 30 female) in the group between 46 and 60 years and 60 patients (30 male and 30 female) in the group older than 60 years.

### 2.2. MRI Evaluation

Standard MRI protocols consist of T1- and T2-weighted sequences with and without fat suppression in coronal, sagittal and axial planes. From these, only the coronal T2-weighted proton density-weighted sequence with fat suppression (spectral attenuated inversion recovery (SPAIR)) were selected. For image viewing and evaluation, OsiriX MD<sup>®</sup> (Pixmeo SARL, Bernex, Switzerland) was used.

In the coronal sequences, the image depicting the decussation of the cruciate ligaments, approximately in the middle of the ACL, was selected [12,27–30]. Based on the description in Hirtler et al. [12], control measurements of the notch width were performed at the level of the popliteal sulcus (NW<sub>p</sub>) and at the level of the joint line (NW<sub>j</sub>). Three shapes were defined and computed as follows: (1) A-shape ( $NW_p < NW_j - 1$  mm), (2) inverse U-shape ( $NW_p = NW_j \pm 1$  mm) and (3)  $\Omega$ -shape ( $NW_p > NW_j + 1$  mm).

Following this, the investigators performed a visual evaluation of the shape of the notch, first without (semi-quantitative evaluation, SqE) and then with a visual aid (assisted semi-quantitative evaluation, aSqE; see Figure 1) on images in a randomized order.



**Figure 1.** Demonstration of the application of a visual guide (green box) in the assisted semi-quantitative evaluation of the IN. (a) A-shaped notch of a 6-year-old patient. Note the difference between NWp and NWj (NWp < NWj). (b) Inverse U-shaped notch of a 30-year-old patient. Note the similar width of NWp and NWj (NWp = NWj). (c) Ω-shaped notch of a 68-year-old patient. Note the difference between NWp and NWj (NWp > NWj).

### 2.3. Statistics

For statistical evaluation, IBM SPSS Statistics software (version 23.0 for Mac OS, IBM SPSS) was used. The metric variables of mean, median and standard deviation were computed. In normally distributed metric variables, the Pearson correlation coefficient was used, and in non-normally distributed variables, the Spearman rank correlation coefficient was used ( $\pm 0.7$  to  $1.0$ , strong;  $\pm 0.5$  to  $<0.7$ , moderate;  $\pm 0.3$  to  $<0.5$ ;  $\pm <0.3$ , weak). For the comparison of metric data, Student's t-test was used in normally distributed variables and the Mann–Whitney U test in non-normally distributed variables. Categorical variables were compared using the chi-square test. Comparisons between the different age groups were investigated using an ANOVA, with a Tukey (homogeneity of variance) or Games–Howell (non-homogeneity of variance) post hoc test. In the case of non-normally distributed variables, a Kruskal–Wallis test with a follow-up Mann–Whitney U test was used. A  $p$ -value of  $<0.05$  was categorized as significant. A Bonferroni correction was performed for multiple tests.

Intra- and inter-rater reliability was investigated. For this purpose, 50 images were randomly collected, and all measurements were repeated one month later. Cohen's kappa coefficient [31] was used to compare the results of the two independent investigators. Following the definition by Altman [32], kappa values were interpreted as follows: 0.81–1.00, very good; 0.61–0.80, good; 0.41–0.60, moderate; 0.21–0.40, fair; and  $<0.20$ , poor agreement.

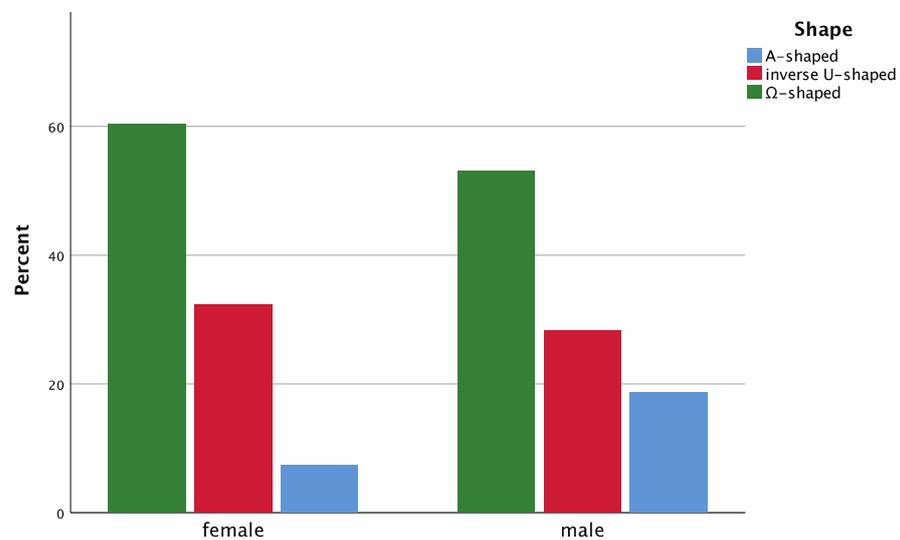
### 3. Results

A total of 330 patients were evaluated (for demographic information, see Table 1). The NWp measured at an average of 18.45 mm (11.60–33.50 mm) and NWj at an average of 17.21 mm (8.30–28.30 mm). Overall, the NWj was significantly smaller than NWp ( $p < 0.0001$ ), and a significant difference between male and female NW was found in both the NWp ( $19.7 \pm 2.94$  mm vs.  $17.17 \pm 2.10$  mm) and the NWj ( $18.75 \pm 3.05$  mm vs.  $15.63 \pm 2.42$  mm) ( $p < 0.0001$ ). No significant difference was found between the left and right knees at either measurement level ( $p = 0.121$  and  $0.439$ ).

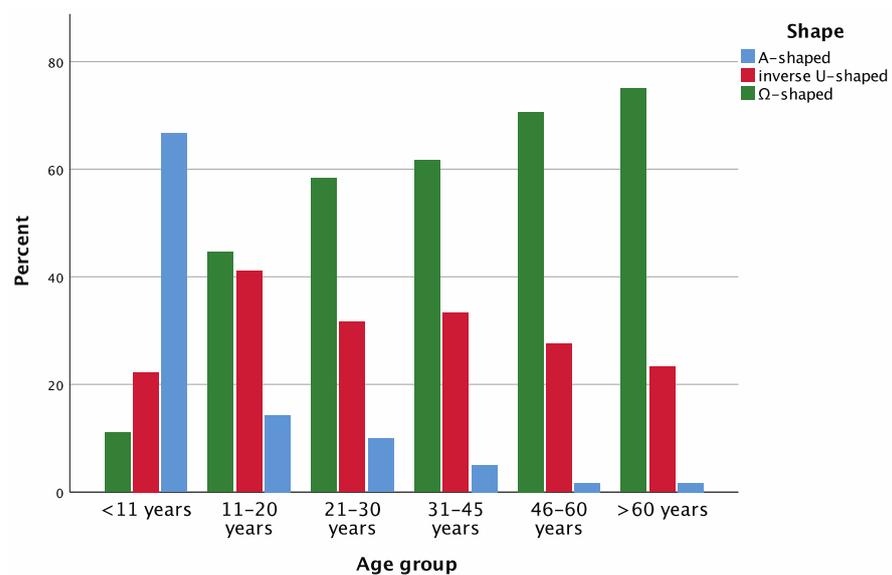
The computed evaluation of the shape of the IN showed 43 (13.0%) with an A-shaped notch, 100 (30.3%) with an inverse U-shaped notch and 187 (56.7%) with an Ω-shaped notch. Significant differences were found in the distributions across sex ( $p = 0.01$ ) and age groups ( $p < 0.0001$ ; see Figures 2 and 3).

**Table 1.** Demographic information on study population.

Age Group (Years)	Side		Total	Notch Width (mm)		Shape		
	Left	Right		NWp	NWj	A-Shape	Inverse U-Shape	Ω-Shape
<11	19 (52.8%)	17 (47.2%)	36	16.13 ± 2.68	17.70 ± 3.19	24 (66.7%)	8 (22.2%)	4 (11.1%)
11–20	24 (42.9%)	32 (57.1%)	56	18.01 ± 2.55	17.17 ± 3.16	8 (14.3%)	22 (41.1%)	25 (44.6%)
21–30	29 (48.3%)	31 (51.7%)	60	18.63 ± 2.69	17.43 ± 3.27	6 (10.0%)	19 (31.7%)	35 (58.3%)
31–45	31 (51.7%)	29 (48.3%)	60	18.96 ± 3.10	17.15 ± 2.98	3 (5.0%)	20 (33.3%)	37 (61.7%)
46–60	33 (56.9%)	25 (43.1%)	58	19.38 ± 2.90	17.36 ± 3.37	1 (1.7%)	16 (27.6%)	41 (70.7%)
>60	30 (50.0%)	30 (50.0%)	60	18.60 ± 2.36	16.61 ± 3.08	1 (1.7%)	14 (23.3%)	45 (75.0%)
Total	166	164	330	18.45 ± 2.85	17.21 ± 3.17	43 (13.0%)	100 (30.3%)	187 (56.7%)



**Figure 2.** Distribution of the three shapes with a significant sex difference between male and female patients ( $p = 0.01$ ).



**Figure 3.** Distribution of the three shapes with a significant difference between the different age groups ( $p < 0.0001$ ).

### 3.1. Semi-quantitative Evaluation (SqE)

First, SqE was performed in all patients. Here, the shape distribution differed significantly from the previously computed classification ( $p < 0.0001$ ). An A-shape was identified in 44 patients (13.3%), an inverse U-shape in 37 patients (11.2%) and an  $\Omega$ -shape in 249 patients (75.5%). Evaluation by Cohens  $\kappa$  showed a fair ( $\kappa = 0.35$ ) agreement between the measured results (results see Table 2). Sex ( $p = 0.299$ ) and age ( $p = 0.070$ ) were not influencing factors.

**Table 2.** Comparison of semi-quantitative evaluation (SqE) and assisted semi-quantitative evaluation (aSqE) with calculated control. Note the significant difference between the results of SqE and aSqE (\*).

Shape	Control	SqE					aSqE				
		Total	Correct	Mistaken As			Total	Correct	Mistaken As		
				A-Shape	Inverse U-Shape	$\Omega$ -Shape			A-Shape	Inverse U-Shape	$\Omega$ -Shape
A-shape	43	44	25	-	6	12	44	41	0	3	0
Inverse U-shape	100	37	19	12	-	69	103	94	4	0	5
$\Omega$ -shape	187	249	165	6	12	-	183	180	0	3	0
Total	330	330	209 *	18	18	81	330	315 *	4	6	3

### 3.2. Assisted Semi-Quantitative Evaluation (aSqE)

Then, all images were randomly evaluated using aSqE (see Figure 1). The shape distribution did not differ significantly from the previously computed shapes ( $p > 0.05$ ). An A-shape was identified in 44 patients (13.3%), an inverse-U-shape in 103 patients (31.2%) and an  $\Omega$ -shape in 183 patients (55.5%). Evaluation by Cohens  $\kappa$  showed a very good ( $\kappa = 0.92$ ) agreement between the measured results (results see Table 2). Sex ( $p = 0.299$ ) and age ( $p = 0.090$ ) were not influencing factors.

## 4. Discussion

The results presented in this investigation reflect the challenges in the shape evaluation of the IN. The hypothesis was only partially confirmed: shape classification was reproducible and performed reliably only with the introduction of visual assistance. In the scope of risk evaluation and clinical applicability, specific and reliable statements concerning the shape of the IN, and, therefore, the prognosis of ligament degeneration or rupture, may only be made when applying rigid and reliable identification guides.

Information on the shape of the IN is important in the assessment of the health of the knee joint, especially when considering risk factors of cruciate ligament rupture or degeneration. As the osseous structures change with age, the shape of the IN changes along with it, rendering it a valuable sign in evaluating risk factors of ligament involvement in the onset and development of osteoarthritis in elderly patients [12,15,33–35]. In addition, the position of the performed NW measurement is of importance. Most often, the NW is measured at the level of the popliteal sulcus [4,12,14,16,17,33]. Hirtler et al. [12] showed that changes to the IN with the development of ligament-endangering ridges, as described by Everhart et al. [19,20], do not occur within the notch but at the level of the osteochondral border, i.e., the joint line [12]. Based on their evaluation of the notch, they identified three shapes (A-shape, inverse U-shape and  $\Omega$ -shape) reflecting the difference between the NW at the level of the popliteal sulcus (within the IN) and that at the level of the joint line (at the osteochondral border).

Although these descriptions of shapes exist and a correlation between specific shapes of the IN and the risk of ligament degeneration and ligament rupture has been proven, no effort has been made to prove the reliability of such risk evaluation [4,12,14,16,17].

Shepstone et al. [35] found a statistically significant difference between the shape of the IN in patients with osteoarthritis of the knee and patients without it. These differences were

mostly found at the lateral intercondylar wall of the medial condyle. The non-osteoarthritic patients showed an overall wave-like shape, and the osteoarthritis patients showed an inverse U-shape. This contradicts the data of Anderson et al. [15], whose patient population showed more pathologies with a wave-like shape rather than with an inverse U-shape.

Considering the less frequently observed problems of the knee joint, such as osteochondrosis dissecans in patients with a discoid lateral meniscus, Kamei et al. [36] showed that in patients with osteochondrosis dissecans, the osteochondral border of the lateral femoral condyle was more prominent (in the direction of an inverse U- or  $\Omega$ -shape) than in patients without osteochondrosis dissecans. Furthermore, several authors [8,37–39] showed that the shape of the lateral wall is of importance when considering possible structures that impinge on the ACL. Nonetheless, there are studies describing the contrary, in which shape evaluation appears to be unimportant, as the categorization of the IN into A- and non-A-shape was not found to reflect any associated risk for ACL injury [3].

The results and discussion in this study demonstrate the diversity of the description of morphological factors, as well as the different conclusions and correlations that may be drawn, depending on the imaging modality, measurement technique and shape definition. The single classification system may reflect this correlation, but its merit is not reflected in clinical application and is subject to personal interpretation.

There are limitations to be mentioned. The MRIs used in this retrospective cross-sectional study were conducted on patients with specific symptoms that warranted imaging. Through the strict application of specific exclusion criteria, intra-articular pathologies interfering with imaging evaluation were avoided. Additionally, the group size of the youngest age group differed significantly from that of all other age groups. However, the risk of ligament pathology in this age group is low, and the applicability of semi-quantitative evaluation with a visual assistance was demonstrated for all age groups.

## 5. Conclusions

In conclusion, shape evaluation, in combination with specific measurements of the NW, is an important tool in the evaluation of the IN. Improving the reliability and the reproducibility of this evaluation requires specifically defined and conducted procedures. During the application of the shape classification of the IN into A-shape, inverse-U-shape or  $\Omega$ -shape, the applicability of this evaluation improved when adding a visual guide for shape identification. This significantly enhanced the number of correct evaluations.

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**Institutional Review Board Statement:** The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the ethics committee of the Medical University of Vienna (1999/2015, 15 December 2015).

**Informed Consent Statement:** Patient consent was waived due to the retrospective design of the study.

**Data Availability Statement:** Not applicable.

**Conflicts of Interest:** The authors declare no conflict of interest.

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