The intercondylar fossa—A narrative review

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Abstract
The intercondylar fossa (“intercondylar notch,” IN) is a groove at the distal end of the femur, housing important stabilizing structures: cruciate ligaments and meniscofemoral ligaments. As the risk for injury to these structures correlates with changes to the IN, exact knowledge of its morphology, possible physiological and pathological changes and different approaches for evaluating it are important. The divergent ways of assessing the IN and the corresponding measurement methods have led to various descriptions of its possible shapes. Ridges at the medial and lateral wall are considered clinically important because they can help with orientation during arthroscopy, whereas ridges at the osteochondral border could affect the risk of ligament injury. Changes related to aging and sex differences have been documented, further emphasizing the importance of individual assessment of the knee joint. Overall, it is of the utmost importance to remember the interactions between the osseous housing and the structures within.

KEYWORDS
femur, intercondylar notch, variation

1 | INTRODUCTION

The intercondylar fossa (“intercondylar notch,” IN), the region between the two femoral condyles, houses major stabilizing structures of the knee joint: the anterior (ACL) and posterior (PCL) cruciate ligaments, the anterior (aMFL) and posterior (pMFL) meniscofemoral ligaments, and pericruciate fat. Because of the intimate relationship between the included ligamentous structures and the osseous structures surrounding them, the term “intercondylar space” was defined to reflect the influences of all these structures on each other (Hirtler et al., 2016).

Several decades ago, the association between the shape and width of the IN and cruciate ligament injury or degeneration was shown to be clinically relevant (Al-Saeed et al., 2013; Anderson et al., 1987; Lund-Hanssen et al., 1994; Palmer, 2007). Additionally, the size of the notch width (NW) correlates with the occurrence of isolated tears in the menisci (Li et al., 2021). Early analysis of these correlations mostly involved measuring various morphological features of the IN on radiographs (Anderson et al., 2001; Herzog et al., 1994; Houseworth et al., 1987; Lund-Hanssen et al., 1994; Schickendantz & Weiker, 1993; Shelbourne et al., 1998; Souryal et al., 1988; Souryal & Freeman, 1993), but no conclusion was drawn. Risk factors for ACL rupture range from the size of the posterior arch of the IN (Houseworth et al., 1987; Kieffer et al., 1984) to its anterior outlet (Lund-Hanssen et al., 1994). Third parties even questioned this correlation (Herzog et al., 1994; Lombardo et al., 2005).

It was Souryal and Freeman (1993) and Souryal et al. (1988) who introduced the notch width index (NWI), the ratio of the notch width (NW) to the bicondylar width (BCW), as a new tool for risk assessment, a standardized method for comparison between sexes, and a way of minimizing bias due to interindividual size differences among patients and the magnification in radiographs (Kocher et al., 2004; LaPrade & Burnett, 1994; Souryal et al., 1988; Souryal & Freeman, 1993). However, this method is still not entirely reliable; the NWI is not standardized in relation to patient body height (Herzog et al., 1994; Lombardo et al., 2005; Schickendantz & Weiker, 1993; Shelbourne et al., 1998).
A summary of the widespread literature about the IN, with the multitude of conflicting arguments about risk assessment for ligament injury, would help to clarify its clinical relevance. Therefore, this review will summarize the major points about the anatomy of the IN, its aging and sex differences, how these affect the risk for injuries and pathological conditions of the knee, and methods for evaluating it.

2 | ANATOMY OF THE IN

Looking at the morphology of the IN (Figure 1A,B) and the corresponding literature, two topics dominate discussions, both with special focus on the ACL. First, there is the morphology of the IN and its influence on the development of ACL injury. Second, there are the ridges in the osseous walls of the notch, which are quite important for orientation during arthroscopy for ACL reconstruction.

2.1 | Shape of the IN

The literature defines its shape in several ways. Ireland et al. (2001) differentiated an A-shaped from a non-A-shaped notch: the former had a significantly larger notch base and a narrowed roof, whereas the latter was rounded, resembling an inverted horseshoe. No correlation with injury status was shown (Ireland et al., 2001; van Eck, Martins, Vyas, et al., 2010). Anderson et al. (1987) differentiated two extreme shapes of the IN: round (inverted U), and steep A-shaped or cresting wave-shaped notches (Figure 2A–E) (Anderson et al., 1987; Keays et al., 2016; Wada et al., 1999). Three additional shapes completed the description of the continuum between those two basic types, bringing the total number of shapes described by Anderson et al to five (Anderson et al., 1987). Tanzer and Lenczner (1990) differentiated among wide, square- and wave-shaped and between stenotic and non-stenotic notches. Van Eck, Martins, Lorenz, et al. (2010), van Eck, Martins, Vyas, et al. (2010), van Eck, Morse, Lesniak, et al. (2010), van Eck, Schreiber, Liu, and Fu (2010), and van Eck, Schreiber, Mejia, et al. (2010) distinguished an A-shaped notch with a narrow apex, a U-shaped notch with a wide apex, and a W-shaped notch that was rather a U-shaped with two apices rather than one (Figure 3A–C). The A-shaped notch was described as stenotic and therefore as a risk factor for ACL injury (Al-Saeed et al., 2013; Fahim et al., 2021; van Eck, Martins, Vyas, et al., 2010). More recently, Hirtler et al. (2016) introduced an age-related classification into A-shaped, Inverse-U and Ω-shaped (Figure 4A–C). As yet there is no clear consensus as to whether to use a shape classification for evaluating patients with knee joint pathologies, and if so, which shape classification to use. Further evaluations concerning the clinical applicability and reliability of such classifications would be warranted.

A changing shape of the IN does not always constitute a risk factor for ACL injury (Anderson et al., 1987; Tanzer & Lenczner, 1990; Tillman et al., 2002); it can also appear as a sign of aging and as an indicator of the development of osteoarthritis (OA) (Hirtler et al., 2016; Shepstone et al., 2001). This makes the evaluation of IN shape even more important for differentiating physiological and pathological conditions. In this differentiation, it is important to focus especially on the osteochondral border, where most of the changes in the IN take place (Hirtler et al., 2016). Here, so-called “ridges” were described by Everhart et al. (2014, 2012), most distinctively an anteromedial ridge, the thickness of which increases with age (Figure 5). This leads to narrowing of the anterior outlet of the IN (Everhart et al., 2012) and significantly increases the strain on the ACL (Durselen et al., 1995; Fleming et al., 2001; Krosshaug et al., 2007; Markolf et al., 1995; Nagano et al., 2007; Oh et al., 2011; Quatman et al., 2011; Shin et al., 2011), rendering it a likely risk factor for the development of ACL injury. Fung et al. (2007) described a similar ridge at the anterolateral osteochondral border of the IN, with the possible consequence of impingement on the ACL. These ridges can be identified in elderly persons as the previously-described Ω-shape (Hirtler et al., 2016).

The reason why this anteromedial ridge develops is not yet clear. It could be due to normal human variation or to biomechanical loading (Everhart et al., 2012). Also, it must be differentiated from osteophytes, which is possible histologically because its dense smooth cortical bone contrasts with the irregular and overhanging morphology of osteophytes (Everhart et al., 2014). However, especially when the IN morphology is examined by imaging techniques alone, it is difficult to distinguish between a “normal” ridge at the osteochondral

FIGURE 1  Skeletal morphology of the intercondylar fossa. (A) View of the distal femur from posterior, (B) view of the intercondylar fossa from distal. L, lateral femoral condyle; M, medial femoral condyle, arrowheads, lateral intercondylar ridge
border and an osteophyte. Only histological examination can make this discrimination reliably, and ridge and osteophyte have approximately the same location.

The anteromedial and anterolateral ridges, as osseous formations at the osteochondral border directly influencing the shape of the IN, have to be differentiated from the ridges located at the insertions of

FIGURE 2  Shape types as described by Anderson et al. (1987). (A) Type 1—U-shape in the left knee of a 29-year-old male patient (3T, axial ePD SAIR), (B) Type 2 in the left knee of a 45-year-old male patient (3T, axial PD SPAIR), (C) Type 3 in the left knee of a 30-year-old male patient (3T, axial ePD SAIR), (D) Type 4 in the left knee of a 28-year-old male patient (3T, axial PD SPAIR), (E) Type 5—cresting wave-shape in the left knee of a 40-year-old female patient (3T, axial T2w TSE)

FIGURE 3  Shape types as described by van Eck, Martins, Vyas, et al. (2010). (A) A-shape in the right knee of a 26-year-old male patient (3T, axial PD SPAIR), (B) U-shape in the right knee of a 22-year-old female patient (3T, axial PD SPAIR), (C) W-shape in the right knee of a 55-year-old male patient (3T, axial PD SPAIR)

FIGURE 4  Shape types described by Hirtler et al. (2016). (A) A-shape in the right knee of a 15-year-old female patient (3T, coronal PD SPAIR), (B) Inverse-U-shape in the left knee of a 20-year-old male patient (3T, coronal PD SPAIR), (C) Ω-shape in the right knee of a 66-year-old male patient (3T, coronal PD SPAIR)
the cruciate ligaments and used as landmarks for tunnel placement in ligament reconstruction.

2.2 | Ridges as landmarks

The detailed morphology of the femoral condyles, the walls of which constitute the sites of origin of the cruciate ligaments, is especially important for reconstruction and for orientation before and during arthroscopic surgery.

On the medial wall of the lateral condyle, the lateral intercondylar ridge (LIR, Figure 1A) is referred to as the anterior border of the ACL in knee flexion. This ridge is also called “resident’s ridge” because inexperienced surgeons can mistake it for the posterior edge of the lateral femoral condyle, leading to incorrect anterior tunnel placement and in consequence to premature failures of ACL reconstruction (Bicer et al., 2010; Ferretti et al., 2007; Hutchinson & Ash, 2003; Petersen & Zantop, 2007; Sasaki et al., 2012; Shino et al., 2010; Zauleck et al., 2014; Ziegler et al., 2011). The lateral bifurcate ridge (LBR) subdivides the footprint of the ACL into its two bundles (Forsythe et al., 2010; Fu & Jordan, 2007; Kopf et al., 2009; van Eck, Morse, Lesniak, et al., 2010; van Eck, Schreiber, Liu, & Fu, 2010; van Eck, Schreiber, Mejia, et al., 2010; Zauleck et al., 2014; Ziegler et al., 2011). Finally, the lateral posterior intercondylar ridge acts as the posterior border of the ACL insertion (Nawabi et al., 2016; Sasaki et al., 2012).

The lateral wall of the medial condyle shows a medial intercondylar ridge (Lopes et al., 2008; Raphael et al., 2011). This is the posterior border of the attachment of the PCL in knee flexion, its anterior border being the osteochondral junction. Here, a medial bifurcate ridge subdivides the attachments of the two bundles of the ligament (Lopes et al., 2008).

3 | EVALUATION OF THE IN

Depending on imaging modalities and specific investigational interests, there are several methods for evaluating the IN. The following paragraphs survey the influence of imaging modalities on the results of measurements, the different measurement parameters, and their reliability in comparison with direct measurements obtained from studies of anatomical specimens or during arthroscopy.

3.1 | Imaging modalities

In plain radiography, the knee is positioned in a tunnel view position (Holmblad 70°, Rosenberg view at 45° knee flexion, at 30° knee flexion, at 20° knee flexion, >80° knee flexion) to reveal the lateral and medial condyles without superposition of other structures and for reliable evaluation of the IN (Ballinger et al., 2003; Boegard et al., 1997; Hernigou & Garabedian, 2002; Herzog et al., 1994; Holmblad, 1937; Keays et al., 2016; LaPrade & Burnett, 1994; Lombardo et al., 2005; Lund-Hanssen et al., 1994; Palmer, 2007; Rosenberg et al., 1988; Schickendantz & Weiker, 1993; Shelbourne et al., 1997; Shelbourne et al., 1998; Shelbourne et al., 2007; Souryal et al., 1988; Souryal & Freeman, 1993; van Kuijk et al., 2021; Vaswani et al., 2020). Nowadays, CT or MRI are most often used for evaluating the IN (Al-Saeed et al., 2013; Anderson et al., 2001; Chen et al., 2016; Davis et al., 1999; Dienst et al., 2007; Domzalski et al., 2010, 2015; Fujii et al., 2015; Hernigou & Garabedian, 2002; Herzog et al., 1994; Hoteya et al., 2011; Sonnery-Cottet et al., 2011; Staubli et al., 1999; Stein et al., 2010; Swami et al., 2013; van Eck, Martins, Lorenz, et al., 2010; Vrooijink et al., 2011; Whitney et al., 2014). These modalities make it possible to reformate the image orientation for better evaluation of the structures and to allow 3D reconstruction. MRI has...
been used most often in recent IN evaluations, although this is not the technique of choice for examining bones; and these images are in any case available because of the patient’s indications, so no additional radiation exposure is required.

3.2 Measurements performed for IN evaluation

In radiographs, a line is drawn tangential to the femoral condyles. Parallel to it, the line for measuring the widths of the IN is positioned according to the investigator’s choice (Table 1). Two notch widths (NW) can be measured in radiographs: the anterior NW and the posterior NW (Lund-Hanssen et al., 1994).

In MRI and CT, most measurements previously obtained from radiographs were adapted for this sectional imaging method, although here too, in addition of choosing either a coronal or an axial oriented slice, the exact positioning of the line of measurement depends on the investigator’s choice (Table 1). The baseline as a tangential line to the femoral condyles is the same as in radiography, irrespective of the orientation of the slice.

In axial images, the image chosen for IN measurements shows the beginning of the roof of the IN in relation to the anterior end of Blumensaat’s line (Anderson et al., 2001; Chen et al., 2016; Stein et al., 2010), the best view of the outline of the entire notch entrance (Vaswani et al., 2019, 2020), or the level of the groove for the popliteus tendon, as in coronal image measurements (Al-Saeed et al., 2013).

In coronal images, the image chosen for IN measurements shows the decussation of the cruciate ligaments, which is most often at the midsubstance of the ACL (Chen et al., 2016; Davis et al., 1999; Domzalski et al., 2010; Swami et al., 2013). The ligaments are said to be at their narrowest here, so they are most vulnerable to rupture at this location (Davis et al., 1999).

Specially reconstructed images are used for measurements at level of the groove for the popliteus tendon (Dienst et al., 2007; Staubli et al., 1999). Also, coronal oblique reconstructions parallel to the anterior border of the ACL and axial oblique reconstructions transverse to the ACL have been described (Whitney et al., 2014).

Recently, Hirtler et al. (2016) showed the importance of the correct choice of measuring level for evaluating the IN. Osseous changes were significantly more frequent at the level of the joint line than at the level of the groove of the popliteal tendon. In particular, Everhart et al. reported that there are ridges at the osteochondral border of the condyles and correlated them positively with the incidence of ACL injury (Everhart et al., 2014). Therefore, the width of the IN at the level of the joint line should be monitored most closely when risk factors for ACL injury are assessed.

Apart from measurements by different imaging techniques, direct measurements in anatomical specimens or during arthroscopy are described (Table 1).

Besides NW measurements, there are several other descriptions of morphometrical parameters including the notch height, the IN angle, the lateral wall angle, the widths of the femoral condyles, the medial to lateral condyle size ratio, the area of the notch, the cross-sectional area of the IN, the width of the cruciate ligaments, the width of the fat between the cruciate ligaments, the volume of the IN, the ridge at the outlet of the IN, notch depth and notch depth index, the width of the notch entrance, the ACL insertion site, etc. (Anderson et al., 2001; Charlton et al., 2002; Davis et al., 1999; Domzalski et al., 2015; Fuji et al., 2015; Hemigou & Garabedian, 2002; Herzog et al., 1994; Jha & Pandit, 2021; Stijak, Radonjic, et al., 2009; Swami et al., 2013; van Eck et al., 2011; Vaswani et al., 2020; Vroojink et al., 2011; Wada et al., 1999; Wang et al., 2021; Whitney et al., 2014; Wolters et al., 2011).

Using the widths of the IN and the distal femur (bicondylar width), the notch width index (NWI) can be calculated as the NW to bicondylar width ratio (Al-Saeed et al., 2013; Chen et al., 2016; Dienst et al., 2007; Domzalski et al., 2010; Herzog et al., 1994; Hoteya et al., 2011; Ireland et al., 2001; Lund-Hanssen et al., 1994; Sonnery-Cottet et al., 2011; Souryal & Freeman, 1993; Souryal et al., 1988; Stein et al., 2010; Swami et al., 2013; Vroojink et al., 2011; Wada et al., 1999; Whitney et al., 2014). The NWI as an absolute parameter can be used for comparing between sexes as it is thought to be standardized for patient size (Charlton et al., 2002). However, the NW does not increase directly with height, in contrast to the bicondylar width, which could replace this parameter as a standardizing tool (Anderson et al., 2001; Shelbourne et al., 1998; Shelbourne & Kerr, 2001). Additionally, Lombardo et al. (2005) reported that the absolute size of the IN did not correlate with an increased risk for ACL injury, questioning the validity of the NWI as a predictor of such injury (Lombardo et al., 2005). Also, Whitney et al. (2014) pointed out that the use of index ratios did not strengthen any of the associations observed using unstandardized measurements. The NWI provides no information about the configuration of the notch (Souryal & Freeman, 1993) and does not correlate with notch volume (van Eck et al., 2021; Whitney et al., 2014; Wolters et al., 2011).

4 PHYSIOLOGICAL AND PATHOLOGICAL VARIABILITY OF THE IN

As the IN houses the major central stabilizing structures of the knee joint, changes to these osseous borders influence the health of those ligaments. These changes range from “physiological,” that is, differences associated with sex and age, to “pathological,” that is, alterations in notch stenosis and due to osteoarthritis.

4.1 Influence of sex

Sex is a major influence on IN morphology, so it is a risk factor for ACL injury. Overall, women sustain ACL injuries 2–8 times more often than males (Arendt et al., 1999; Harmon & Ireland, 2000; Henry & Kaeding, 2001). One reason could be the up to 40%–50% smaller cross-sectional area and mass of the ACL, resulting in a higher stress load during movement in females (Chandrashekar et al., 2005;
Additionally, differences in knee flexion angles between males and females have been reported during sports requiring cutting, landing or jumping movements. Anterior tibial translation in the knee joint is maximal at flexion angles below 30°, so the ACL is most often injured at low flexion angles; control of anterior tibial translation in

| Modality                | Measurement of NW                                                                 | References                                                                                                      |
|-------------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|
| Plain radiography       | In the middle of a line perpendicular to the baseline                            | Lund-Hanssen et al. (1994), Hernigou and Garabedian (2002), Shelbourne et al. (2007)                           |
|                         | At the groove of the popliteal tendon                                             | Souryal et al. (1988), Souryal and Freeman (1993), Herzog et al. (1994), LaPrade and Burnett (1994), Shelbourne et al. (1997), Ireland et al. (2001), Lombardo et al. (2005), Hoteya et al. (2011) |
|                         | At two thirds of the depth of the IN                                              | Herzog et al. (1994)                                                                                            |
|                         | At the level of the articular margins                                            | Herzog et al. (1994)                                                                                            |
| MRI and CT              | **Axial**                                                                        |                                                                                                                   |
|                         | At the level of the groove of the popliteal tendon                                | Herzog et al. (1994), Al-Saeed et al. (2013), Lima et al. (2020)                                               |
|                         | At site with minimum NW                                                          | Hoteya et al. (2011)                                                                                            |
|                         | At one third of the depth of the IN                                               | Alentorn-Geli et al. (2015), Vaswani et al. (2020), Jha and Pandit (2021)                                      |
|                         | At two thirds of the depth of the IN                                              | Herzog et al. (1994), Anderson et al. (2001), Stein et al. (2010), Chen et al. (2016), Vaswani et al. (2020)   |
|                         | At the level of the articular margins                                            | Herzog et al. (1994), Hemigou and Garabedian (2002), Vaswani et al. (2019, 2020)                              |
|                         | At half the depth of the IN                                                        | Al-Saeed et al. (2013)                                                                                         |
|                         | At the region near the ACL attachment site                                        | Hoteya et al. (2011), Whitney et al. (2014), Chen et al. (2016)                                               |
|                         | Posterior to the ACL attachment site                                              | Hoteya et al. (2011), Whitney et al. (2014)                                                                   |
|                         | At the groove of the popliteal tendon                                              | Herzog et al. (1994), Davis et al. (1999), Domzalski et al. (2010), Sonnery-Cottet et al. (2011), Vrooijink et al. (2011), Swami et al. (2013), Domzalski et al. (2015), Fuji et al. (2015), Chen et al. (2016), Hirtler et al. (2016), Pekala et al. (2019) |
|                         | At one third of the depth of the IN                                               | Alentorn-Geli et al. (2015), Jha and Pandit (2021)                                                            |
|                         | At two thirds of the depth of the IN                                              | Herzog et al. (1994)                                                                                            |
|                         | At the level of the articular margins                                            | Herzog et al. (1994), Hirtler et al. (2016)                                                                   |
|                         | At the inlet of the notch                                                          | Whitney et al. (2014)                                                                                         |
|                         | At the outlet of the notch                                                         | Whitney et al. (2014)                                                                                         |
| Direct measurements in anatomical specimens | At the anterior outlet                                                            | Wada et al. (1999)                                                                                            |
|                         | At width of the IN at two-thirds of the notch depth                               | Wada et al. (1999)                                                                                            |
|                         | At width of the IN at the midpoint of each third                                 | Tanzer and Lenczner (1990)                                                                                     |
|                         | At the width of the IN at the level of the groove for the popliteus tendon        | Stjäk, Radonjic, et al. (2009)                                                                                  |
| Direct arthroscopic measurements | Entrance at the base, the middle and the top of the IN                          | Wolters et al. (2011), Vaswani et al. (2019, 2020), Wang et al. (2021)                                        |
those movements has been shown to be of major importance. In combination with the reported significant neuromuscular imbalance between the quadriceps femoris and the hamstring muscles, this indicates an inherent difficulty in decelerating from a landing, and controlling the anterior tibial translation has been identified as a further pathophysiological factor in women (Quatman et al., 2010).

These sex differences entail a major problem: the correct use and interpretation of metric parameters and indices during comparisons. No statistically significant difference between men and women in the NWI or other ratios has been reported (Anderson et al., 1987, 2001; Chandrashekar et al., 2005; Charlton et al., 2002; Domzalski et al., 2010; Gormeli et al., 2015; Hirtler et al., 2016; LaPrade & Burnett, 1994; Tillman et al., 2002), whereas metric values (notch width, bicondylar width, width of the femoral condyles, notch volume) are significantly greater in males than females (Anderson et al., 1987; 2001; Davis et al., 1999; Everhart et al., 2012; Hirtler et al., 2016; Ireland et al., 2001; Shelbourne et al., 1997; Souryal & Freeman, 1993; Staubli et al., 1999; Stijak, Nikolic, et al., 2009; Swami et al., 2013; van Diek et al., 2014; van Eck, Martins, Lorenz, et al., 2010; Vrooijink et al., 2011; Wolters et al., 2011). This sex difference in the size of the NW is rather easily explained, as it is positively associated with height and weight (Anderson et al., 2001; Charlton et al., 2002; Dienst et al., 2007; Everhart et al., 2014; Shelbourne et al., 1998; Whitney et al., 2014).

4.2 Influence of age

Aging alters the morphology of the knee joint (Figure 6A–D). From the age of three to 17 years the NWI grows smaller, from 0.326 in the youngest to 0.25 in the eldest (Anderson et al., 2001; Domzalski et al., 2015; Herzog et al., 1994; Lima et al., 2020; Pekala et al., 2019). Everhart et al. (2014) also described a positive age-related change in the size of the anteromedial ridge at the osteochondral border of the notch. Specimens under the age of 15 showed no ridge; it grew ever more discernible in the older age groups; and over age 35 the ridges were at least

![Figure 6](image-url)
1.0 mm thick (Everhart et al., 2014). Hirtler et al. (2016) described a retrospective cross-sectional study of the IN. They showed that these changes do not stop after completion of growth but continue into great age and are more marked at the level of the joint line than at the level of the groove for the popliteus tendon, which is the measurement level most often used in the literature. Through their subclassification of the shape of the IN, these authors assigned three specific shapes to different stages of life: A-shape in children, Ω-shape in elderly persons, and inverse-U-shape in between. This opens a totally new field of investigation: age-specific evaluation of risk factors for knee joint injury when healthy and injured probands of the same age group are compared.

4.3 | Notch stenosis

Notch stenosis is the main osseous cause for ACL injury. This is relevant not only to the initial development of ACL injury, but also to rerupturing of the reconstructed graft and degenerative changes to it (Ahn et al., 2007; Fuji et al., 2015; Herbst et al., 2017; Mayr et al., 2017; Mueller et al., 1999; Tuca et al., 2021). However, there is currently no overall agreement about a cut-off value for IN measurements. The recommended benchmarks for identifying IN stenosis range between 15 mm and 17 mm for the notch width (Lombardo et al., 2005; Lund-Hanssen et al., 1994; Shelbourne et al., 1997; Souryal & Freeman, 1993; Stein et al., 2010) and between 0.18 and 0.27 for the NWI (Al-Saeed et al., 2013; Domzalski et al., 2010; Gormeli et al., 2015; Hoteya et al., 2011; Keays et al., 2016; LaPrade & Burnett, 1994; Lombardo et al., 2005; Shelbourne et al., 1997; Sonnery-Cottet et al., 2011; Souryal & Freeman, 1993; Stein et al., 2010; Uhormack et al., 2003).

Everhart et al. (2014) showed that the aforementioned anteromedial ridge is age-dependent and is involved in the development of notch stenosis. Even during its early development it was responsible for a certain percentage of notch stenosis cases (Everhart et al., 2014).

Leon et al. (2005) classified four types of intercondylar stenosis on the basis of the arthroscopic correlation of osseous changes with ACL injury, without relying on specific measurements or osseous parameters. Type I (anterior type) was detected in 29% of patients who showed injury on the anterior-distal area of the ACL due to an ACL-notch mismatch. Type II (lateral type) was identified in 20% of patients with injuries in the midlateral area of the ACL. Type III (mixed type) injured the anterior-distal and midlateral portions of the ACL in 48% of patients; and type IV (massive type), found in 3% of patients, is defined as severe intercondylar stenosis with complex injury to the ACL that is not covered by the other three types.

In ACL reconstruction, some authors therefore suggest performing a notchplasty in combination with reconstruction of the ligament itself in order to minimize the rerupture and failure rates and the postoperative development of a so-called cyclops formation (Ahn et al., 2007; Asahina et al., 2000; Dienst et al., 2007; Fuji et al., 2015; Herbst et al., 2017; Iriuchishima et al., 2013; Keklikci et al., 2013; Mayr et al., 2017; Mueller et al., 1999; Orsi et al., 2017; Tuca et al., 2021).

This summary of the literature shows the wide range of possible open questions concerning IN morphology and the border between healthy and pathological INs. Existing data provide no basis for clear instructions.

4.4 | Influence of osteoarthritis

Osteoarthritis is diagnosed in up to 30% of the population over the age of 65 in the western world (van Saase et al., 1989). The knee joint is affected early in 6% of adults aged 30 years or more and in at least 13% of adults aged 60 or more, leading to morphological changes and ligament destruction (Cham et al., 1991; Dunlop et al., 2001; Felson et al., 2000; Hill et al., 2005; Link et al., 2003; Stein et al., 2010).

Owing to the complexity and socioeconomic importance of OA there is a large body of literature concerning different risk factors, several of them being anatomical variations and age-related changes, the IN constituting one of them. A general widening and flattening of the condyles on the medial side (“elephant’s foot,” Figure 7) in combination with osteophytic growth in the vicinity of the osteochondral and osteosynovial border and a narrower notch are identifiers for OA in the distal part of the femur (Cham et al., 2016; Marshall, 1969; Neogi et al., 2013). These osteophytes are most frequent at the lateral and superior margins of the IN (Good et al., 1991) and narrow the IN as the OA progresses (Wada et al., 1999).

FIGURE 7 Elephant’s foot at the lateral femoral condyle; osteoarthritis in a 73-year-old male patient. 3T, coronal eT1w TSE
These osteophytic changes in OA not only change the osseous morphology of the IN but also influence the ACL, leading to progressive impingement of this ligament during joint movement and ultimately to disruption of it and its proprioceptive feedback (Leon et al., 2005; Sharma & Pai, 1997; Staebuli et al., 1999). Combined with a certain inhibition of the quadriceps femoris muscle (Snyder-Mackler et al., 1994) and altered joint kinematics, this leads to the further progression of degeneration (Dye & Cannon, 1988; Shepstone et al., 2001).

Wada et al. (1999) compared the influence of an injured ACL on the dimensions and morphology of the IN in patients with OA. NW and NWI were significantly smaller in patients with ACL problems than in those with a healthy ACL, and also correlated positively with the severity of the OA (Kellgren and Lawrence grades 3 and 4 vs. grades 1 and 2: Kellgren & Lawrence, 1952, 1957). Ruptures were most often complete in patients with Kellgren and Lawrence grade 4. It also seemed that osseous growth of the femoral condyles proceeded anteroposteriorly, widening the femoro-tibial contact area and thus increasing the stability of the knee joint in this direction. This helps to explain the increasing joint stiffness in more severe OA (Brage et al., 1994; Marshall & Olsson, 1971; Sharma et al., 1999; Wada et al., 1996, 1999). This anteroposterior and vertical growth of osteophytes in OA therefore contributes to the development of an ACL tear (Wada et al., 1999). Also, deterioration of the ACL during the progression of OA further promotes joint degeneration, especially as the development of ligament laxity in the knee precedes the formation of osteophytes (Quasnichka et al., 2005), constituting a vicious circle.

5 | SUMMARY

Changes to the intercondylar fossa, either physiological or pathological, influence the structures within, that is, the cruciate ligaments and the meniscofemoral ligaments. To interpret this part of the distal femur as static would be unwise, as the literature shows changes not only during growth but throughout life. These changes can sometimes have consequences for the stabilizing ligaments within. Correct assessment of the risk involved requires in-depth knowledge of the osseous anatomy and its changes throughout life in combination with a strategic and clinically applicable evaluation system. In particular, the combination of measurements of the notch width and determinations of the shape of the intercondylar fossa could delineate the risk for ACL injury and thus influence further treatment of the patient.

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