Physiopathology of Patello-femoral Osteoarthritis: Current Concepts

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ABSTRACT
Patellofemoral osteoarthritis (PFOA) is the result of degeneration and loss of articular cartilage of the patella and trochlea, and is a common cause of anterior knee pain. PFOA is triggered by insufficient adaptation to overload of the articular cartilage of the PF joint created by abnormal biomechanics. It is important to understand the pathophysiology and natural history to make the diagnosis and to plan treatment. Innate factors including malalignment, patellar instability, kinematic disorders, and acquired factors like trauma, obesity, and endocrine diseases have been found to be causes of PFOA. Genetic predisposition is also described as a contributing cause but without much scientific evidence. The diagnosis will be based on clinical manifestations, such as anterior knee pain aggravated by overloading activities, identification of risk factors, exclusion of referred pain from other pathologies, followed by a systematic and structured physical examination. Imaging will be useful for assessing the presence of early osteoarthritis in the other compartments, for classification of the PFOA, and to identify features to establish an adequate treatment. This paper discusses varying management options for different causes of patellofemoral disease and explains the complexity of the PF joint and its often poorly understood biomechanics.

CURRENT CONCEPTS

- Patellofemoral osteoarthritis (PFOA) is one of the most frequent causes of anterior knee pain.
- The causes for patellofemoral osteoarthritis can be innate or acquired.
- It remains difficult to achieve agreement on the best treatment.
- Surgeons must make a careful assessment to determine the origin of the patellofemoral osteoarthritis (PFOA) and guide the best treatment options.

FUTURE PERSPECTIVES

- It is necessary to design and conduct prospective randomized long-term studies to determine the best outcomes following treatment for each cause of patellofemoral osteoarthritis (PFOA) by analyzing functional and clinical results.
- Current studies offer a mix of diagnoses that can mislead results.
- More and better genetic studies are needed to assess predisposition for patellofemoral osteoarthritis (PFOA).
INTRODUCTION

Knee osteoarthritis is a chronic joint disease with a major impact upon the activities of daily living leading to a decrease in quality of life. Researchers have focused on understanding tibiofemoral osteoarthritis, but the role of the patellofemoral joint in knee osteoarthritis is becoming more recognized (1,2). The patellofemoral and the tibiofemoral joints show different structural, pathomechanical, and clinical characteristics, resulting in different patterns of risk factors (3). It is well known that patellofemoral (PF) osteoarthritis (OA) is a common cause of pain arising from the patellofemoral joint. An increasing amount of research is being conducted into the causes, different treatment options, and outcomes of surgery.

PFOA is the result of degeneration and eventually full-thickness loss of the articular cartilage lining the patella and trochlear groove (4) and is seen more frequently in females and in patients over age 55 (5). To date, no study has evaluated the prevalence of PFOA. Prevalence of PFOA in people with knee pain aged 30 years and older was 39%, approximately 40% of people with PFOA in the population-based cohorts had the disease isolated to the patellofemoral compartment only and roughly one-fifth in the symptom-based cohort, (2). Osteoarthritis of the patellofemoral joint has been more frequently observed than the tibiofemoral joint and may present as an isolated entity or part of a generalized knee OA (6,7). Complete loss of cartilage involving the PF joint is debilitating and often leads to surgical treatment (6,8).

There are four types of PFOA, with the lateral type being the most common and is associated with PF dysplasia, with or without patellar instability. The medial type is associated with genu varum as well as previous surgical procedures, including lateral patellar release or medializing tibial tubercle osteotomies. Global type patellofemoral osteoarthritis is related to primary osteoarthritis, post-traumatic (usually patellar fracture), or systemic inflammatory diseases. Central trochlear OA is associated with high-flexion demand patients (3).

It has been suggested that PF pain syndrome in the younger years may lead to PF arthritis in later life (9), and accordingly it is important to understand the pathophysiology of the
patellofemoral disease and its natural history in order to plan a treatment during its various stages of presentation (10).

PHYSIOPATHOLOGY

Patellar cartilage has different biochemical and mechanical properties compared with the articular cartilage of the tibia and femur. The complexity of the PF joint is based on static elements including the medial and lateral patellofemoral and patellotibial ligament complexes and dynamic elements influenced by lower limb alignment, rotational variances, muscle strength, and pelvic position related to the knee. Abnormalities of one or a combination of these factors is associated with PFOA (10). Despite these factors, patellofemoral pain is still a paradigm in the etiology of PFOA.

Cartilage properties

The articular cartilage of the patella is thicker, softer, and more permeable compared to articular cartilage elsewhere in the body, including the trochlea (10). However, in terms of the fluid and solid components or phases, it is like all other articular cartilage.

The solid phase is slightly permeable, formed by collagen arcades containing highly negatively charged glycosaminoglycan molecules, which repel one another and, provided they remain within their collagen arcades, are highly effective in resisting compressive forces. During articular surface loading, fluid distributes gradually within the solid matrix (4,11).

The cushioning effect of the articular cartilage and the low friction coefficient are explained by the pressure within the fluid and the smooth outer surface. Any injury of the outer articular surface, such as fissures, crevices, or cracks, decreases the pressure of the fluid phase and this increases the stress on the collagen fibers, leading to breakdown and eventual erosion of the articular cartilage and resulting in wear and mechanical damage (4,10,12,13). PF arthritis is more prevalent in the lateral patellar facet, which would indicate that this facet would be more overloaded than the central or medial facet (14).

Mechanical testing and microscopical imaging are used to probe the effects of cartilage degeneration, but each component cannot be separated directly (15). The fibril-reinforced
The poroelastic (FRPE) model is a finite element model that captures the dynamic mechanical behavior of the cartilage (16). This model provides new insights about cartilage wear and lubrication, especially in the PF joint, which carries high loads, and is useful to characterize mechanical properties of artificial cartilage (13).

It is suggested that patellofemoral pain leads to PFOA. Patients with patellofemoral pain have been shown to have patellae with elevated bone water content, increased hydrostatic pressure, elevated metabolic activity, and decreased patellar cartilage thickness that leads to degenerative changes (17). Biomarkers in PFOA are a measurable indicator of a pathophysiological process associated with the progression of the disease. The use of biomarkers to identify early changes could be useful in monitoring PF damage (18). The best-studied OA biomarkers include collagen type II C-telopeptide (CTX-II) and cartilage oligomeric matrix protein (COMP), which are released as a result of the breakdown of articular cartilage. Inflammatory factors, such as IL-6 and TNF-a, as well as metabolic ones, such as leptin, insulin, and adiponectin are all potentially measurable biomarkers (17). Whilst biomarkers are not approved for the diagnosis and treatment of PFOA, their use and correlation with clinical and imaging findings will provide a better understanding of the disease (18).

Patellofemoral pain and PFOA may form a continuum of disease. Altered loads in the PF joint are seen in patients with PF pain, with subsequent cartilage and osseous changes. The loss of the homeostasis in patellofemoral tissues is a proposed etiology of patellofemoral pain. Studies have suggested that cartilage degeneration is accompanied by a decrease in venous outflow. However, there is no evidence that a decrease of blood supply either preceded or succeeded degenerative changes (19).

One study found morphological and structural changes associated with ischemia, such as hypervascularization and increased vascular endothelial growth factor release in the lateral retinaculum in the painful PF joint (20). Tissue hypoxia releases neural growth factor and substance P, which leads to hyperinnervation and may generate pain.

Some authors have proposed that the patellofemoral joint is exposed to loads that often exceed the threshold for biologic tissue load acceptance and others that the sympathetic nervous system could be involved (20).
Biomechanics of the PF joint related to osteoarthritis

The biomechanics of the PF joint is unique. It is quite different from the tibiofemoral joint, especially in the magnitude and distribution of the pressure that provides pathogenetic implications (1).

In simple terms, PFOA occurs because the articular cartilage is insufficiently able to adapt to the overload created by the abnormal biomechanics of the patellofemoral joint. Abnormal biomechanics leads to a disturbed transmission of forces in the PF joint and focal areas of increased load, more commonly on the lateral patellar facet. Wear of the articular surface occurs and ultimately leads to clear deterioration of the PF joint.

It is important to recall that the patella has a complex articulation and moves with respect to the femur in three planes. This produces different forces acting against the patellar surface during flexion and extension with varying contact areas and pressure changes on the PF surface (21,22).

In the frontal plane, in extension, the patella lies slightly lateral to and above the trochlea. With flexion, load on the patellar surface commences, with initially the more inferior part articulating and then more proximally as the patella travels distally in the trochlea (22). The quadriceps angle (Q-angle) is the resultant force orientation of the four components of the quadriceps muscles acting on the patella and results in a lateralizing force being generated with this resulting force potentially causing subluxation of the patella. However, this is resisted by a medial force applied predominantly by the muscular (VMO) and ligamentous (MPFL) structures but also the trochlea. The lateralizing force is greater in the valgus knee where the tibial tubercle sits more laterally and may lead to secondary osteoarthritis (21,23) (Fig. 1). In the horizontal plane, the distribution of forces is homogeneous in a normal joint, but when the patella is lateralized, the resulting force is greater on the lateral facet, leading to an overload of the lateral articular surface (21,24) (Fig. 2). In the sagittal plane when the knee moves through a full range of motion, the patella moves over approximately twice its length. During this movement, the patella is positioned posterior to the tibial tubercle and deeper at the center of the trochlea. The
Patella in flexion is pulled distally by the relatively inelastic patellar tendon resulting in different areas of contact and pressure (21). Forces are provided by the quadriceps muscles, which move the patella upwards, and the patellar tendon, which pulls it downwards, with the resulting force generating compression of the patella against the femur. When these forces are disproportionately large or unevenly distributed across both sides of the patella, the resulting loads will eventually produce PFOA (22,24) (Fig. 3). Contact pressures in the PF joint changes throughout the range of motion, starting at 15°–20° of flexion where the patella is on track; as flexion increases, the contact area moves proximally on the patella (25).

PF joint stability is provided by static structures (capsule, quadriceps and patellar tendon, medial and lateral ligaments) and dynamic structures (quadriceps muscles, core muscle, and hip external rotators). It is important to remember that small changes in alignment and stability can alter patellofemoral joint stresses.

The quadriceps muscles in particular vastus medialis obliquus (VMO) and vastus lateralis (VL) have an important role to control patellar alignment and coronal plane position. During activities, it has been shown that VMO and VL have a synchronous function (26). Reduction of VMO activity and increases in VL activity results in a lateral patellar malalignment and an increase in lateral PF pressure (27). Patients with patellofemoral pain show a delayed onset of VMO activation relative to the VL during stair-stepping tasks and in isokinetic knee extension. (1). Until now, there have been no studies that demonstrate that a delay in the onset of VMO is evident in PFOA. Hamstring tension is relevant—it has been shown that loading medial and lateral hamstrings simultaneously rotates the tibia externally increasing lateral tilt of the patella, thus increasing the lateral facet contact force (28).

There’s some evidence that reduced hip abductor strength is related to PFOA with one study showing that isometric hip abductor strength is 25% lower in patients with PFOA (28). Midfoot mobility may be related to a higher prevalence of medial PFOA, but more work is required to fully understand and elucidate this relationship.

The position of the femoral trochlea and the tension in the soft tissues may affect patellar tracking, while femoral internal rotation and tibial external rotation are associated with increased lateral tilt and lateral PF pressure. The Q-angle represents a laterally directed
force vector that results in 60% more load on the lateral patellar facet than the medial facet. An increase in the Q-angle will lead to an increase in the lateral contact area and pressure of the PF joint (29).

CAUSES OF PATELLOFEMORAL ARTHRITIS

PFOA may be caused by innate or acquired factors (6). Innate causes include anatomical factors or kinematic disorders in the PF joint, while acquired causes include trauma, overload associated with obesity, and some endocrine diseases. Malalignment and patellar instability can be both innate and acquired factors.

Malalignment

An inadequate fit of the surfaces of the patella and trochlea is referred to as patellar maltracking and results in an abnormal load distribution across the joint and eventually leads to arthritis (10). Merchant et al. (30) and Ficat et al. (31) have described a tight lateral retinaculum with consequent patellar tilt and increased pressure on the lateral patellofemoral compartment.

Currently, there are no prospective studies demonstrating that patients with tibiofemoral malalignment have a greater predisposition to PF osteoarthritis, but there is evidence that patients with isolated PF osteoarthritis often have malalignment (10).

An increased or decreased Q-angle leads to increased pressure on the patella and the lateral or medial trochlea surface. Additionally, abnormal internal distal femoral torsion leads to an increase of pressure on the lateral aspect of the PF joint (10).

Patellofemoral dysplasia

Trochlear dysplasia is a morphological abnormality in the shape and depth of the trochlear groove. A dysplastic trochlea leads to abnormal patellar tracking and is associated with PF instability in early years whilst an inadequate distribution of loading increases the risk of PF osteoarthritis in later years (32,33).
The morphology of the trochlea affects the extensor mechanism in knee flexion and extension. This abnormal shape produces increased loads on the patella with a combination of increased compression, shear stress, and lateral overload leading to patellar cartilage wear (1,34).

Jungmann et al. (32) demonstrated that trochlear dysplasia with a shallow trochlea and abnormal sulcus angle was associated with a reduction of the patellar cartilage volume, suggesting that trochlear dysplasia is related to a more severe form of PF osteoarthritis.

The key to diagnosis of trochlear dysplasia is a true lateral radiograph where the two femoral condyles are superimposed. The principal feature is the crossing sign, which represents a convergence and then crossing of the deepest part of the trochlea and the anterior projection of the lateral femoral condyle. These two lines remain parallel and distinctly separate in the normal knee. The further distal the crossing occurs, the more severe is the dysplasia. Other radiological features include a supratrochlear spur, which is a bony projection anteriorly on the proximal trochlea, and the double contour sign, which is a linear cortical projection of the anterior cortex into the condyles and indicates advanced trochlear dysplasia involving the medial condyle (5).

Trochlear dysplasia can be classified into four types based on these characteristics (33,36,38) (Fig. 4). Patients in categories B, C, or D are at the greatest risk of developing PFOA, with trochlear dysplasia being present in 78% of knees with isolated patellofemoral arthritis (4,36,38). There is a strong correlation between the degree of dysplasia and the severity of arthritis with the presence of a supratrochlear spur presumably having an effect by increasing PF pressure (37). While patella alta has a strong relationship with patellar instability, as an isolated factor it is not related to the development of PF osteoarthritis.

**Instability**

The association between patellar subluxation, which is the partial loss of congruence between the patella and trochlea in the axial plane, and the development of arthritis has not yet been formally described. However, there is evidence that following a first episode of patellar dislocation, there is a higher likelihood of developing PF osteoarthritis (39,40). It remains unclear whether PF realignment surgery, which is acknowledged as resolving...
patellar instability, will delay or prevent PFOA and this remains a controversial matter (41,42). Some studies have shown that patients who have undergone surgical treatment for patellofemoral instability demonstrate a higher rate of PF arthritis compared to patients treated nonoperatively (43,44), possibly because successful surgery for instability allows the patient to resume the activities that eventually lead to arthritis in the same manner as with successful ACL surgery. The current literature on this issue is difficult to interpret given the wide spectrum of patellar instability patients, variations in the types of trochlear dysplasia, and the many differing surgical procedures (41).

More consistency in reporting and more evidence are necessary to determine whether patellar stabilization surgery, with or without articular cartilage treatment, has a positive or negative impact on the development of PF osteoarthritis.

Acquired

Direct trauma to the front of the knee will result in changes to the patella articular cartilage and this may occur with or without patellar fracture and potentially predispose to the development of patellofemoral OA. However, at this time, there is no study that has determined the threshold of trauma applied to the front of the knee that is required to cause permanent damage to the patellar articular cartilage (10). Obesity, with a BMI greater than 30 kg/sqm can predispose to patellofemoral pain (10,45,46) and lead to patellofemoral osteoarthritis (47,48). While it is not known whether a high activity level leads to patellofemoral OA, there are some endocrine diseases associated with the development of patellofemoral OA. These include insulin resistance and diabetes as well as hypothyroidism and adrenocortical insufficiency, which are all related to a chronic inflammatory interaction within the endocrine system. This inflammatory process may predispose to lower limb weakness and an increase in loads on the patellofemoral joint with subsequent wear (6,49). A genetic predisposition to deterioration of the articular cartilage has also been described, but scientific evidence for this is lacking (10,50). Ethnic groups have different genetic predispositions for developing OA, which may explain the variability of PFOA prevalence across different regions (2).

There is no evidence that degeneration of the patellar cartilage is associated with repeated kneeling or squatting activities (6). In addition, there is no evidence to suggest elevated cases of PFOA is seen in Asian countries where squatting for toileting is common. The
reverse may be true with some literature showing that increased contact area between the femoral trochlea and patella during kneeling could be a protective factor preventing patellofemoral osteoarthritis (2,51).

DIAGNOSIS

Clinical manifestations

Patients often tolerate patellofemoral OA for a long period with no specific symptoms until it becomes more advanced (52). Anterior knee pain is the first and most important symptom, aggravated by activities that load the bent knee, such as both ascending and descending stairs, kneeling, squatting, and standing from a seated position. Patients usually describe crepitus and sometimes creaking as well as stiffness when first walking after a period of being seated and sometimes a sense of locking (4,53). A thorough history is important to determine the etiology, including a past patellar dislocation, fracture, or previous surgeries (21,24). It is important to exclude referred pain from hip and spine and other pathologies such as synovitis, quadriceps or patellar tendinosis, plica syndrome or other focal articular cartilage lesions (54,55).

Physical examination should follow a structured and systematized approach to confirm the diagnosis. While we describe examination of the knee with patellofemoral symptoms, it is important to always examine the hip to rule out referred pain to the knee and to check for features of radicular pain from the lumbar spine (56,57). Physical examination is dependent on the examiner and can be influenced by the patient’s level of pain (58). There are many clinical tests and scores available for the examination of the patellofemoral joint (56,57).

With the patient standing, observe the patient’s alignment and the gait pattern. There is frequently a quadriceps sparing gait. Quadriceps muscle strength can be assessed manually or by a dynamometer (1). In the standing position, the examiner will observe the Q-angle, rotational alignment of the femur and tibia, and foot posture, while looking for the presence of squinting patella or a lateral tilt (4,56,59) (Figs. 5,6,7). The position of the patella in relation to the femur is observed in extension, and then when the patient is seated with the knee flexed over the side of the exam couch, patellar tracking is
observed as the patient extends the knee. In the presence of trochlear dysplasia, J tracking is seen.

With the patient in a supine position, quadriceps atrophy of more than 2 cm, the presence of an effusion, and retro patellar crepitus with motion should be assessed (23,60). The presence of crepitus, although not a conclusive sign of arthrosis, is sought (61). With the knee in full extension, the patella is subluxated slightly to the sides and both patellar facets can be palpated (5,21,56). Tenderness over medial and lateral patellar facets is a major sign of patellofemoral osteoarthritis. The proximal to distal site of the articular lesion can be determined by the degree of flexion of the knee where pain occurs. With a more distal lesion, pain will occur at a lower degree of flexion than with a proximal lesion.

Clarke’s test, or the patellar grind test, is positive when there is pain as the patient contracts the quadriceps while the examiner applies compression of the patella against the trochlea. This test has a low sensitivity and a high rate of false positives (56,62) (Fig. 8).

**Imaging**

For patellofemoral osteoarthritis, standing anteroposterior view, Rosenberg view (tunnel view at 45°), lateral view, and Merchant view (skyline view) can be assessed. As discussed above, a true lateral view at 30° degrees is the most reliable image for diagnosing trochlear dysplasia and assessing patellar height. The Merchant view at 25°–30° is useful to assess patellofemoral joint-space narrowing in the proximal patellofemoral joint as it demonstrates the contact between patella and trochlea (4,21,52). There are many radiographic classification systems to describe the degenerative cartilage lesion for the patellofemoral joint. Those described by Iwano and also by Merchant are the most commonly used and classify PFOA into four stages based on skyline view (63,64,65). However, Kose et al. have shown unsatisfactory intraobserver reliability in all PFOA classifications (66) (Figs. 9-10).

A weightbearing Rosenberg view is useful to assess joint space narrowing in the posterior part of the medial and lateral femorotibial compartments. The use of CT scan is recommended to identify features of a past lateral patellar dislocation, femoral trochlear dysplasia, patellar tilt, and an offset between tibial tuberosity (TT) and trochlear groove
Magnetic resonance imaging (MRI) is useful for assessing the presence of early osteoarthritis in the other compartments, particularly when isolated PF arthroplasty is being considered in younger patients (3,12,63). The assessment must record the presence of patella alta, patellar dysplasia, or any traumatic condition (53).

Discrepancies remain in the definition and methodologies for the diagnosis of PFOA. A lack of consistency among researchers and clinicians when grading features of the patellofemoral joint may explain why the studies vary widely in reported prevalence using radiographies or MRI studies (2,67,68). Few authors have evaluated the PF compartment specifically, to determine patient selection or to evaluate treatment. Most trials refer to patients with OA as a homogeneous group. Clinical guidelines need to individualize OA strategies of management to optimize outcomes (1,69).

CUTTING-EDGE TECHNOLOGIES FOR PFOA

It is important to develop alternative diagnostic tools that are less expensive, noninvasive, and more precise for diagnosing the early stages of PFOA (70).

Vibroarthrography

Vibroarthrography (VAG) is a measurement of the sounds or vibrations generated during movements of the knee joint and has achieved > 90% accuracy in detection of OA. Changes in the structure of the cartilage surface affect the vibroacoustic modulation signals, which are produced by transient elastic waves generated by stress redistribution in the material (70). However, the use of vibroacoustic diagnostics in daily practice remains unreliable and further development and studies are necessary before it will be a useful tool in diagnosing PFOA.

Latest advancements in imaging in OA

While previous imaging of OA was restricted to conventional radiography, recent technologies have been introduced, such as compositional MRI, positron emission tomography (PET-MRI), weightbearing computed tomography (WBCT), multiscale X-
ray phase-contrast tomography, and advanced ultrasound techniques. Most recently, even
the use of artificial intelligence (AI) in imaging of PFOA has become available (71).

Compositional MRI provides information of early cartilage damage and can detect
collagen, water content, and proteoglycans, but requires standardization of the MRI
 technique for clinical application. PET-MRI has the ability to detect metabolic activity
such as bone remodeling and inflammation whilst WBCT is useful for early detection and
management of lower limb OA particularly for hindfoot and tibiotalar OA (72). None of
these technologies are immune to the high cost of the equipment and for WBCT, elevated
radiation exposure. It is expected that in the future, AI will improve the precision and
interpretation of the images.

CONCLUSION

PFOA is one of the most frequent causes of patellofemoral pain, and determination of its
cause is essential to optimally manage the patient. Abnormal biomechanics can lead to
severe degeneration of the articular cartilage. Treatment strategies aim to create normal
load transmission and distribution for optimal performance. Surgeons need to consider
the biomechanical basis of PF osteoarthritis in order to plan the most appropriate
treatment option to correct biomechanical abnormalities. Innate causes such as
malalignment, instability, or trochlear dysplasia have good results with surgical
treatment. More high-level studies are required to reach consensus on diagnostic criteria
and to establish the most appropriate management for each of the known causes of PFOA.
Prospective randomized long-term studies analyzing functional and clinical results will
help determine the best treatment for each cause of patellofemoral osteoarthritis. New
technologies for the early diagnosis of PFOA will become the cornerstone of future
investigations.

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FIGURE 1

Fig 1: Acting forces of the extensor mechanism in the frontal plane. The patella lies slightly lateral to and above the trochlea. The quadriceps angle (Q angle) is the resultant force orientation of the four components of the quadriceps muscles acting on the patella and results in a lateralizing force.

FIGURE 2

Fig 2: Compression forces of the patella on the trochlea. The morphology of the trochlea contributes to medialization and these actions combined increases the lateral patellar tilt. In a normal joint the distribution of forces is
homogeneous, but when the patella is lateralized, the resulting force is greater on the lateral facet leading to an overload of the lateral articular surface.

**FIGURE 3**

Fig 3: Forces acting on the knee in the sagittal plane. Forces are provided by the quadriceps muscles which move the patella upwards and the patellar tendon that pulls it downwards with the resulting force generating compression of the patella against the femur.
FIGURE 4

Fig 4. Dejour’s Classification for trochlear dysplasia
**FIGURE 5**

Fig 5.- Observe the patient standing and barefoot, check alignment, recurvatum and foot posture.

**FIGURE 6**
Fig 6.- In a sitting position describe the presence of patellar tilt (grasshopper eye)

FIGURE 7

Fig 7- Palpate medial and lateral facet of the patella

FIGURE 8
Fig. 8. Clarke’s test or the patellar grind test is positive when there is pain as the patient contracts the quadriceps whilst the examiner applies compression of the patella against the trochlea.

FIGURE 9

Fig. 9 IWANO classification for PFOA

FIGURE 10

Fig. 10. Imaging of PFOA in CT scan and MRI
Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: