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ON THE DEVELOPMENT OF ADVANCED METHODOLOGIES TO ASSIST ON THE DIAGNOSIS OF HUMAN ARTICULATIONS PATHOLOGIES: A BIOMECHANICAL APPROACH

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ABSTRACT: *The main purpose of this investigation is to present a preliminary study on the development of advanced methodologies to assist on the diagnosis of human articulations pathologies. In this process, a biomechanical approach is considered to characterize the patellofemoral joint. The present research work involves two distinct scientific domains, respectively, engineering and health sciences, and arises as a result of an association between the Mechanical Engineering Department of the University of Minho and a Portuguese company of medical consulting, ESPMEN. The correlation of both of these areas takes part of the highest biomedical engineer's research interests and professional ambitions. One area where this kind of approach is essential is in the understanding of patellofemoral disorders, due to their ambiguous definition, multifactorial aetiology and common thread with and impact on nearly all knee conditions. Thus, the present project represents an appealing challenge to all the involved parts. This paper describes the patellofemoral (PF) problems, from their physiopathology to epidemiology, focusing their critical question: the diagnosis, but from a conclusive perspective of resolution. Actually, since the majority of the PF cases are recurrently misdiagnosed, there is in fact an urgent need of standardization of the physical examination methods. The biomechanical approach should prospectively culminate in the development of a standard assessment methodology that could precisely diagnose the PF pathologies and moreover allow clinicians to apply the most accurate and personalized treatment to each patient.*

1 INTRODUCTION

Patellofemoral (PF) joint, as an integral part of the knee, is one of the most complex articulations of the human body with high functional and biomechanical requirements. Anatomical and physiological abnormalities of the PF joint result in knee problems with high social incidence and intensity. Therefore, their correction might prevent or

delay the development of PF arthrosis, decreasing their long-term health-economic and life-quality negative impacts. Clinical history, physical examination and imaging studies should be complementary procedures in the diagnosis of PF disorders, especially considering that these are the most neglected, complex and problematic knee problems. However, it has been recognized by many clinicians that the efficiency of physical tests still remains unclear and unreliable and, for that reason, they frequently misdiagnose these cases. Thus, this work focuses on the characterization of the diagnosis of PF disorders. The remaining of this work includes a detailed description of the physiopathology, epidemiology and diagnosis of the PF joint which will play a key role in the biomechanical appeal purposed.

2 PHYSIOPATHOLOGY

2.1 ANATOMY AND BIOMECHANICS

The knee is a complex articulation, which bony structure consists of femur, tibia, fibula and patella. The patella is the largest sesamoid bone of the human body, a movable unique bone that is wrapped inside a tendon that connects the quadriceps muscle (Q-muscle) to the lower leg bone (tibia) through another tendon (patellar tendon), composing the quadriceps mechanism [1-4]. Along with its counterpart, the patellar groove of the femur (also known as femoral groove), the patella constitutes the PF joint (see Fig. 1).

As an integral part of the knee, PF joint is one of the most structurally complex articulations with high functional and biomechanical requirements [1-4]. It has to withstand compression and tension forces (for example, releases the tension around the femur, by transferring these forces to the patellar tendon), playing a major role to flexion and extension movements of the knee [1, 4-6]. Patella acts as a biological lever arm in transmitting the force of the quadriceps muscles and centralizing their divergent forces, consequently improving their effective extension ability by increasing the moment arm of the patellar tendon [4, 6, 7]. Complementarily, patella has an aesthetic function for the human leg and forms a bony shield, protecting the tibiofemoral joint of the knee [1, 4].

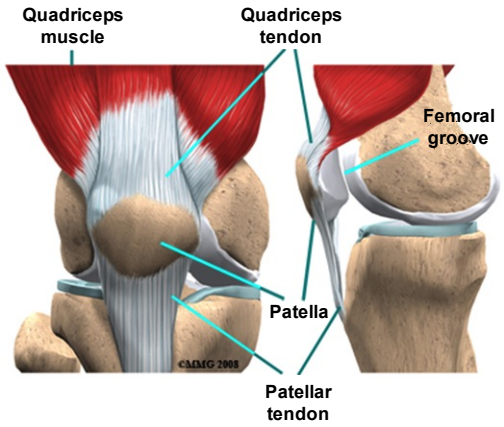

Fig. 1 Illustration of the patellofemoral joint and identification of its constituents. Adapted from [8]

2.2 PATHOLOGIES

Anatomical and physiological abnormalities of the PF joint may be the cause for multiple clinical problems of the knee [1, 9], usually associated with anterior knee pain. Patellar syndrome (PS) and patellar instability (PI) are the pathologies related to the PF joint. In which respects to PS, it is not associated with dysplasia. On the other hand, PI encompasses dislocation and subluxation of the patella and results from several biomechanics abnormalities and factors [9-14]:

a) Osseous abnormalities, such as:
   - Patella *alta* – high ratio of the lengths of the patellar tendon and the patella: LT/LP > 1.2;
   - Distance of ≥ 20 mm between the tibial tubercle and the trochlear groove (TT-TG);

- Trochlear dysplasia – trochlear groove > 150º, inexistent or convex;

b) Soft-tissue abnormalities, such as:
   - Torn medial patellofemoral ligament (MPFL);
   - Weakened *vastus medialis obliquus* (patella tilt > 20º).

Patellar instability can also be classified in primary, objective and major patellar instability, according with each specific manifestation of factors and related to the occurrence of episodes of patellar dislocation, respectively: no episodes, one or more dislocations, and usual or permanent dislocations (being really unstable) [2, 7, 9, 10, 14].

3 EPIDEMIOLOGY

3.1 INCIDENCE

PF problems constitute the most common knee complaint and are more frequent between adolescents and young adults, in both athletic and nonathletic population, although being more incidents in the first one, especially in women [3-5, 12, 15].

3.2 SOCIAL IMPACT

Osteoarthritis, also known as arthrosis, is characterized by pain and dysfunction of the joints, predominantly affecting the knee [16]. It is the leading joint disease, the major cause of disability and one of the most common predictors of health problems (osteoarthritis of the knee is present in approximately 40% of the adults older than the age of 70), in both developed and developing world [17]. Hence, prevention or delay on the development of PF arthrosis is crucial and may be achieved by the correction of structural abnormalities of PF articulation [12, 18].

Despite its high incidence, intensity and long-term impact in the society, anterior knee pain is, however, the most neglected, the least known and the most problematic and complex pathological knee condition [3]. This arises from several factors [19]:

- Biomechanical complexity of the PF joint;
- Lack of correlation between symptoms, physical and radiological findings;
- Discrepancy in the definition of what is considered normal;
- Multifactorial aetiology (*Medicine*: science that deals with the causes or origin of disease, the factors which produce or predispose toward a certain disease or disorder [20]).

Consequently, the limited aetiopathogeny knowledge is reflected in difficult diagnosis and assessment of these cases, being recurrently misdiagnosed [3, 21, 22]. The resultant diagnostic errors are serious and can even lead to unnecessary interventions [3].

4 DIAGNOSIS

4.1 CLINICAL HISTORY AND PHYSICAL EXAMINATION

PF disorders are initially diagnosed on clinical history and physical examination [10]. This physical examination results from some physical tests applied to the patient, whose validation is governed by the manifestation of pain by the patient, not showing any accuracy, precision and reproducibility of the methodology. Nowadays, there is a wide range of clinical tests, outcome measures and means of calculating scores and scales, described in the literature, used to diagnose and assess PI [21-24], such as the following indexes:

- Insall-Salvati – ratio calculated by dividing the length of the patellar tendon (LT) by the length of the patella (LP) [25];

- Modified Insall-Salvati – which is based on the difference between the distal end of the articular surface of the patella and the patellar tendon insertion on the tibia and the length of the articular surface of the patella [26];
- Blackburne-Peel – method that measures the ratio of the articular surface length of the patella to the height of the lower pole of the articular surface above a tibial plateau line [27];
- Caton-Deschamps – measures the distance between the distal point of the patellar articular surface and the anterosuperior border of the tibia divided by the length of the articular surface of the patella [28, 29];
- Labelle-Laurin – which defines a patella as *alta* if its proximal pole lies above the tangent of the ventral cortical line of the femur on a lateral X-ray in 90º of knee flexion [30].

The sensitivity/specificity as well as the reliability/validity of these diagnostic tests and outcome tools have been evaluated, but it still remains unclear [10, 20, 22]. In general, the majority of the tests are more useful qualitatively than quantitatively. Furthermore, usual poor inter-observer reliability may be due to differing examination methods around the world [22]. Therefore, there is no supported accuracy and validity for the existent methods and none is suitable for universal application.

4.2 IMAGING STUDY

The second diagnostic step is the imaging study. There is a wide variety of imaging techniques that can be applied on the systematic study of this articulation, each one of them having various advantages and disadvantages. Standard radiographs, computed tomography (CT) and magnetic resonance imaging (MRI) are the most common applied techniques for the diagnosis by image [31, 32, 33]. However, only magnetic resonance imaging (MRI) allows the simultaneous evaluation of all the structures that constitute the complexity of PF joint, being the most complete and perfect imaging technique. On the other hand, also the computed tomography (CT) is essential because it allows the quantification of small bone defects in a reliable, fast, simple and easily reproducible way [31, 33]. The imaging results allows then the measurement and quantification of the indexes described above in **4.3** [12]. Consequently, the aforementioned diagnostic phases should be taken as complementary procedures, having a correlation in between and never replacing each other to obtain the final diagnosis.

5 CONCLUSION

In short it can be said that there is the need of standardization of physical examination procedures, both performance and recording. Thus, it will be possible to construct a reproducible assessment methodology, feasible and reliable, that more precisely diagnose the PF pathologies. Furthermore it will allow the clinicians to make a pre-sorting, respectively forwarding the patient to the most correct and appropriate treatment, such as rehabilitation, avoiding complex surgical intervention, according to each clinical case.

The methodology should be compatible with MRI and CT procedures, in order to perform the physical examination simultaneously and complementarily with the imaging diagnosis, which is essential as abovementioned. The design, development, functional and clinical validation of a medical device with the above mentioned characteristics are the next steps of this investigation, coupled with a standard diagnosis criteria designation. It is expected that this work will represent a great significant evolution with respect to the diagnosis of the PF problems, once it

represents something not available yet in the market neither patented nor published before.

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