General

Meniscal extrusion: risk factors and diagnostic tools to predict early osteoarthritis

Giuseppe Francesco Papalia[1,2], Pierangelo Za[1,2], Luca Saccone[1,2], Edoardo Franceschetti[1,2], Biagio Zampogna[1,2], Sebastiano Vasta[1,2], Rocco Papalia[1,2]

[1] Department of Orthopaedic and Trauma Surgery, Università Campus Bio-Medico di Roma, Roma, Italy, [2] Research Unit of Orthopaedic and Trauma Surgery, Fondazione Policlinico Universitario Campus Bio-Medico, Rome, Italy

Keywords: Meniscal extrusion, Early Osteoarthritis, Root Tears, Diagnosis tools

https://doi.org/10.52965/001c.74881

Orthopedic Reviews

Vol. 15, 2023

Meniscal extrusion (ME) is strongly correlated with cartilage wear and osteoarthritis (OA), be-cause of the altered kinematic and the decreased contact area between the tibia and femur. The aim of this narrative review is to analyze the process of ME, focusing on the possible causes, and to evaluate the correlation between ME and knee OA, in order to provide early diagnosis and treatments. Studies written in English that analyzed the causes of ME, provided indications re-garding diagnosis and treatment, and evaluated the relation between ME and early OA were in-cluded. Injuries, degeneration of the meniscal substance and meniscus root tears are associated with significantly increased ME. An extruded meniscus could be a manifestation of other pa-thologies such as disruption of coronary ligaments, cartilage loss, knee malalignment, ligament injuries, or OA. ME is strongly associated with osteoarthritis features, particularly with bone marrow lesion and cartilage damage. Magnetic resonance imaging represents the gold standard for the detection of ME. The severity of the medial meniscus extrusion may also affect healing af-ter repair, and meniscus extrusion is not completely reduced by meniscus posterior root tear re-pair. In this study, we proved that ME represents an important risk factor for early knee OA. We provided alternative theories of ME, such as meniscal fibers injury first and “dynamic extrusion of the menisci”. The phenomenon of aging has been described as a new concept in the etiology of ME. Finally, we stated all the main techniques and characteristics of the diagnostic process, as well as the current knowledge in the therapeutic field.

1. INTRODUCTION

It has been widely demonstrated the relationship between meniscal loss of function and osteoarthritis (OA).[1] Particularly, meniscal extrusion (ME) is strongly correlated with cartilage wear and OA.[2] In absence of a functional meniscus, it has been shown exposure to pathologic loads of articular cartilage of the knee, with consequent degeneration.[3-5] The menisci are c-shaped wedges of fibrocartilage positioned between femoral condyles and the tibial plateau. The upper surface of the menisci is concave, while the lower is flat; they then stabilize knee joint by the conversion of tibial articular surface into a shallow socket. These features lead the menisci to absorb shocks, decrease friction, supply stability, nutrition, lubrication, and proprioception, spread load and increase congruity of the knee joint. Biomechanical analyses have demonstrated that at least 50% of the compressive load of knee joint is transferred by the menisci in extension, while almost 85% of the load is transferred at 90° of flexion, reducing the mechanical stresses on cartilage surfaces and subchondral bone.[6,7] With the load applied, normal menisci physiologically flatten by transmitting the stresses and extrude to various degrees (up to 3 mm), in diverse directions to neutralize the forces. Disruption of collagen fibers, which provide hoop strength, eventually results in diminished biomechanical properties leading to pathological meniscal extrusion.[8] Currently, the pathological ME also known as meniscus subluxation or displacement is described as a deviation of the meniscus of 3 mm or more than 30% of total meniscal width beyond the edge of the tibial plateau.[9-11] ME represents an important risk factor in the premature development and progression of OA,[12,13] because of the altered kinematic and the decreased contact area between tibia and femur, the articular cartilage of the knee is so exposed to pathologic loads and subsequently degenerates. Therefore, an early diagnosis and treatment of ME can bring a deceleration in the evolution of the OA process, with a reduction in number of patients who need total knee arthroplasty (TKA) procedures, and consequently reducing the economic burden by the health system. The aim of this narrative review is to analyze the process of ME, focusing on the possible causes, and on the relevance of early diagnosis and treatments. Moreover, another goal of this study is to evaluate the cor-

relation between ME and knee OA, to provide to knowledge in the therapeutic field to slow down the degenerative arthritis process.

2. MATERIALS AND METHODS

A literature search was conducted using Scopus, Cochrane Central and PubMed–Medline, Cochrane Central, Scopus, and Google Scholar. The following search strings were used: (“meniscal”[All Fields] OR “menisceal”[All Fields]) AND (“extrusion”[All Fields] OR “extrusions”[All Fields]). We included studies written in English that analyzed the causes of ME, provided indications regarding diagnosis and treatment of this pathology and evaluated the relation between ME and early OA.

3. RESULTS

Degeneration of the meniscus, injuries, and meniscal root tears are associated with significantly increased ME.[14,15] However, an extruded meniscus could represent not only a meniscal tear, but should be an expression of other pathologies such as disruption of coronary ligaments, cartilage loss, knee malalignment, ligament injuries, or osteoarthritis.[16]

3.1. RISK FACTORS FOR MENISCAL EXTRUSION

Kenny firstly identified that medial displacement occurs at the level of the firm attachments to the deep medial ligament and medial capsule.[17] Muzaffar et al.[18] associated the meniscus type of lesion to the extrusion rate and showed that ME is correlated with medial meniscal posterior horn tears (64.26% of evaluated patients), followed by medial meniscal body tears (21.42%), medial meniscal root tears (5.1%), lateral meniscal body tears (9.18%) and lateral meniscal posterior horn tears (4.08%). Crema et al.[9] in a total of 2131 knees have demonstrated that ME in both compartments is significantly related to meniscal tears, particularly to root tears in medial compartment. Moreover, they proved that varus and valgus alignment are independent factors associated with medial and lateral ME. However, Zhang et al.[19] demonstrated that higher body mass index (BMI), meniscal tear, varus alignment, knee injury history, Heberden’s nodes, mild knee symptoms and Kellgren-Lawrence (KL) grade ⩾1 at baseline were significantly associated with an elevate degree of medial meniscal body extrusion. Novaretti et al.[20] reported that patients with higher BMI had significantly higher ME compared to patients with normal BMI ($p < 0.001$). In a cross-sectional study by Zhang et al.,[21] it has been found a correlation between ipsilateral meniscus tear, BMI and medial ME in a sample of 395 women with a mean BMI of 32.4 kg/m^2. In a study by Ding et al.[22] was found the positive association between medial ME and the following values: BMI, weight, tibial bone area, medial tibiofemoral cartilage defect score, radiographic OA, medial joint space narrowing and osteophytes, loss of medial tibial cartilage volume, and progression of tibiofemoral cartilage defect score. Kim et al.[23] included in their study patients with tear of medial meniscus treated with arthroscopic partial meniscectomy. Preoperatively, they showed that the extension of meniscal degeneration and the pattern of meniscal tear were related to meniscal extrusion. Furthermore, they found that menisci degeneration grade was directly proportional to meniscal extrusion. Finally, the degree of ME had a statistically significant correlation with IKDC subjective score and IKDC radiographic grade.

3.1.1. ROOT TEARS

Many studies have shown the correlation between ME and root tears.[24-27] Meniscal root tears are described as bony or soft tissue root avulsion injuries or radial tears within 1 cm of meniscus root attachment.[28-30] The meniscal roots play a crucial role to convert axial tibio-femoral loads into hoop stresses.[31] Therefore, the loss of meniscal anchoring to the tibial plateau causes loss of meniscus function, knee kinematics alteration and ME. The medial meniscus posterior root tear (MMPRT) leads to abnormal biomechanics of the tibiofemoral joint and the inability to turn axial loads into hoop stresses, inducing medial ME,[29,31] and resulting in a condition similar to total meniscectomy.[30,32] Finally, the presence of ME on magnetic resonance imaging (MRI) is considered one of the three criteria for the diagnosis of root tears.[33]

3.1.2. LATERAL MENISCUS

Laprade et al.[28] in a cadaveric study demonstrated that avulsions of the posterior root attachment of the lateral meniscus and radial tears adjacent to the root attachment significantly decreased the contact area and increased the contact pressure in the lateral compartment of the knee. however it is a cadaver model in which its impossible to reproduce normal tissue biology, including muscle contractions, proprioception, and healing. However, in the cadaver model of was impossible to reproduce normal tissue biology, including muscle contractions, proprioception, and healing. Minami et al.[34] investigated 317 patients with a previous anterior cruciate ligament (ACL) injury. The group with lateral meniscus posterior root tear (LMPRT) showed significantly greater meniscus extrusion than the control group. However, the chronological cause and effect relationship between LMPRT and meniscus extrusion has not still been described in detail. Moreover, the authors did not clarify whether meniscal extrusion may play an additional role in anterolateral rotational instability in anterior cruciate ligament-injured patients. Kamatsuki et al.[35] demonstrated the association between posterior root tears and ME in 35 knees with ACL injury. They showed that a complete lesion of the posterior root of the lateral meniscus causes a greater ME than a partial lesion of the same root in presence of insufficient ACL. Moreover, the authors found that a meniscal extrusion of 1.1 mm on MRI could predict posterior lateral root injury with a sensitivity of 100% and specificity of 83% for complete LMPRT in knee with an ACL tear.

3.1.3. MEDIAL MENISCUS

The medial meniscus is more susceptible to injury and extrusion than the lateral meniscus due to its anatomical characteristics and because it is a relatively less mobile structure. Lerer et al.[15] evaluated patients with medial ME and found significant associations between pathological extrusion, loss of articular cartilage, and a posterior root tear of the medial meniscus that resulted in loss of meniscal function. Sung et al.[36] reported that the mean absolute medial ME was 4.1±0.7 mm in 36 knees showing the MMPRT at a mean of 5.3-months from the onset of symptoms. Furthermore, Furumatsu et al.[37] demonstrated that the mean absolute medial ME was 3.0±1.2 mm even in the early period (less than one month after the MMPRT onset), and that medial ME developed progressively within one year after the onset of symptomatic MMPRT. However, it is still unclear if extrusion occurs as a result of meniscus root tears or if root tears are the final result of damage to secondary meniscal restraints and associated extrusion.

3.1.4. MENISCOTIBIAL LIGAMENTS

Krych et al.[38] proposed that an initial meniscal extrusion is the consequence of a progressive loss of functionality of the meniscotibial ligaments. Thus, with the progressive loss of function of the meniscotibial ligaments, the posterior root is subjected to increasing forces that can lead to its breakage and a further deterioration of meniscal extrusion. The final result is the rapid degeneration of cartilage and the progression to osteoarthritis. In a previous study, Krych et al.[39] showed the correlation between meniscotibial ligaments injury and meniscal extrusion. They analyzed 3244 MRI of patients with ME and only 20 of this had an isolated ME (0.62%), showing that an isolated ME is a very rare finding. Meniscotibial ligaments abnormalities were detected in 65% of cases (13 of 20). Patients with a meniscus extrusion of more than 3 mm were much more likely to present associated meniscotibial ligament abnormalities (100%, 9 of 9) in comparison with patients with < 3 mm of extrusion (36%).

3.1.5. DYNAMIC EXTRUSION

The difference in extrusion between unload and load conditions was described as dynamic extrusion.[40] Due to its viscoelastic properties, the meniscus can deform itself reversibly, when subjected to axial forces.[41] In fact, under load the collagenous fibers of the meniscus elongate and subsequently increase the hoop stress,[14] while after unloading the meniscus returns to its original position. Therefore, both an enhanced ME and a reduced or absent functional adaption reaction of the meniscus can be considered pathological.[42] The physiological dynamic behaviour is crucial for the meniscal function and it is the consequence of shock absorption and load distribution by the meniscus.[43] The forces are transmitted in circular hoop stress, which is transferred to the insertions of the menisci.[44] The absence of a natural meniscal extrusion shows a lack of meniscal function, as it happens in case of root tears, in a condition described as "the dead meniscus" by Karpinski et al.[42] Furthermore, they hypothesized that dynamic ME is a physiological finding in the healthy meniscus and it is decreased in knees with medial root tear. They used ultrasound to compare the dynamic ME in presence of medial root lesion compared with healthy patients. The patients were examined first in supine position and after in full weight bearing condition. In the experimentale group, the mean medial ME was 3.6 mm (± 1.0 mm) in the supine position, while in the standing position it increased to 3.7 mm (± 0.9 mm). The mean δ-extrusion was 0.1 mm (± 0.2 mm) and the ratio was 1.0 (± 0.1). Instead, in controls, the mean medial ME was 1.3 mm (± 0.3 mm) in the supine position and increased to 2.3 mm (± 0.4 mm) under bipedal standing with full weight-bearing. Therefore, the mean δ-extrusion in this group was 1.0 mm (± 0.4 mm) and the extrusion ratio was 1.8 (± 0.4). In conclusion, they demonstrated that medial root tear determines a significant reduction of dynamic ME in comparison with healthy meniscus status, resulting in a phenomenon called "dead meniscus sign".

3.1.6. KNEE MALALIGNMENT

Knee malalignment causes suboptimal load distribution among the menisci, knee joint cartilage and subchondral bone, resulting in increased risk of injuries and accelerate OA.[45] Crema et al.[9] and Lefevre et al.[46] proved that varus malalignment is an independent factor associated with ME. Conversely, Chang et al.[47] et Erquicia et al.,[48] did not find a correlation between varus malalignment and ME.

3.2. AGING

Achtnic et al.[40] evaluated the phenomenon of aging, demonstrating that ME is present also in healthy knees and that is closely related to age. Therefore, the meniscal deterioration could be attributed not only to acute traumatic injuries or to lesions but also to the phenomenon of aging on degenerated meniscus. Aging can be defined as a result of a time-dependent accumulation of molecular and cellular damage,[49] that involves all the structural components of the meniscus. Aging can hit a particular type of cells, called meniscal chondrocytes, that produce the type 1 collagen, responsible for resisting hoop stresses. The mechanism of age-related tears is not fully understood, but a stiffened meniscus with compositional changes might become vulnerable to degeneration or damage with repetitive loading or microtrauma. Thus, the loss of this defense mechanism could facilitate the meniscal extrusion in a meniscus otherwise devoid of tears. However, although the mechanism of cellular senescence is well recognized, it is not clear whether this can negatively affect the quantity and quality of collagen.

3.3. DIAGNOSTIC TOOLS FOR MENISCAL EXTRUSION

In presence of meniscal extrusion, it results essential to obtain an early diagnosis, in order to avoid the progression to OA. Symptoms associated with meniscal extrusion are non-specific and may be affected by any associated injuries. Usually, the patient shows up with swelling, pain sometimes discontinuous and not always well located at the joint line, popping or clicking. Given the not-specificity of the clinical framework, the evaluation of the imaging is fundamental. Imaging modalities used to detect ME include plain radiographs, ultrasound and MRI.

Radiographs should be obtained in a weight-bearing position and provide indirect evidence of meniscus extrusion, evaluating the joint space narrowing and the presence of buttressing osteophytes.[50]

Ultrasound does not expose to ionizing radiation, displays the knee joint line and leads to evaluate body meniscal integrity and possible meniscal extrusion.[51] Extrusion was described as the distance between a tangent line parallel to the fiber orientation of the medial collateral ligament (MCL) at the margin of the medial tibial cortex and the outermost edge of the medial meniscus.[42,52] However, it is not effective for the assessment of the tibiofemoral cartilage or for the direct evaluation of meniscal anterior and posterior horns or roots. Nevertheless, Mureşan et al.[53] demonstrated in a prospective study with athletes that static ultrasound examination of medial meniscal lesions by an experienced examiner has a specificity of 77.7% and a sensitivity of 88.8%. Moreover, in a study by Verdonk et al.[54] ultrasound and MRI were used to examine dynamic lateral meniscus extrusion in patients after meniscus transplantation. They showed that both the measurement devices are adequate for evaluating laterally directed extrusion of the normal and transplanted lateral meniscus.

MRI is highly sensitive and specific and represents the gold standard for the identification detection of meniscal degeneration, tears and extrusion.[14,41] Both 1.5- and 3-Tesla MRI scanners provide diagnostic-quality images of the meniscus.[55,56] Proton Density weighted sequences are optimal for the assessment of meniscal pathology. The study of meniscal extrusion at MRI is influenced by the load, which led to a better definition of meniscal pathologies compared to MRI assessed in the supine position.[57] Meniscal extrusion can be identified and measured at the mid-coronal slice, choosing the slice with the largest area of medial spine. A first line is drawn perpendicular to the medial edge of the tibial plateau, and a second line is drawn perpendicular to the most edge of the medial meniscus; ME is calculated as the distance between those two lines, excluding osteophytes.[16] Jones et al.[11] demonstrated that the single coronal MRI slice overestimates the real value of the ME, because it sets the greatest ME at the anterior part of the tibia. On the contrary, the coronal MRI slice corresponding to the apex of the medial tibial spine detects most closely the true perpendicular extrusion measures. Medial ME can be graded as a relative percentage of extrusion: with grade 0=no extrusion, grade 1=⩽50% extrusion and grade 2= >50% extrusion[9,58]; or as part of semi-quantitative MRI scoring systems for OA, with grade 0= <2 mm; grade 1=2–2.9 mm, grade 2=3–4.9 mm; grade 3= >5mm.[19,59] Indeed, lateral ME can be measured using the coronal slice in which the femoral attachment of the popliteal tendon was best visible, as the horizontal distance between the most external margin of the tibial plateau articular cartilage and the peripheral border of the lateral meniscus.[57,60] A threshold of 3 mm is usually observed to discriminate between physiological and pathological extrusion. In fact, ME greater than 3 mm on mid-coronal imaging is significantly correlated with articular cartilage degeneration, severe meniscal degeneration and root tears.[33] However, this threshold of >3mm displacement of the body of medial meniscus in documenting ME may not be entirely correct,[61] because physiological ME depends on different parameters, like age and BMI,[40] and could be completely reversible.[62] Therefore, the quantitative distinction between physiological and pathological extrusion remains unclear. Svensson et al.[63] sustained that the use of 3mm cut-off as radiological limit to define pathological ME can lead to overestimating the true cases. Thus, they proposed a new 4mm cut-off, claiming that the use of this new value could lead to a higher number of true positives, with higher specificity on MRI as a marker of structural OA features.

3.4. TREATMENT OF MENISCAL EXTRUSION

Conservative treatment for isolated or degenerative ME includes physical therapy, rehabilitation, and intra-articular corticosteroid or hyaluronic acid injections in order to maintain range of motion and provide short-term relief of knee pain. When ME is associated with other injuries such as radial tears or root tears, these could be repaired. It is still unclear if it is advantageous to repair an isolated meniscal extrusion. The severity of the medial meniscus extrusion may also affect healing after repair,[64] and medial ME is not completely reduced by MMPRT repair.[65] Root tears are strongly correlated to ME, but conflicting results have been shown concerning the progression of medial ME after arthroscopic transtibial pull-out repair of MMPRT. Krych et al.[66] in their prospective multicenter study found that meniscal extrusion worsened six months after meniscal root repair. In fact, mean extrusion increased significantly, from 1.9 ± 1.5 mm preoperatively to 2.6 ± 1.4 mm postoperatively. However, in this study, the pull-out technique to restore the meniscal root seems to be effective in slowing down the cartilage degeneration process. Moon et al.[67] retrospective analyzed 63 patients who underwent isolated arthroscopic transtibial pull-out repair of medial meniscus root tear. According to MRI medial ME ratio after surgery, the patients were divided into two groups, distinguish for increased or reduced/maintained meniscal extrusion ratio. They noted a statistically significant improvement in clinical outcomes 2 years after surgery, without significant differences between the 2 groups. Nevertheless, MRI findings showed osteoarthritis progression at postoperative 2 years, which was significantly higher in the group of patients with an increased meniscal extrusion ratio. Finally, better clinical outcomes were found when surgery

was performed within 13 weeks from the onset of symptoms; therefore, they suggest that performing early surgical repair of medial meniscus root tear may avoid the progression of ME and osteoarthritis. Kaplan et al.[68] evaluated the mid-term functional outcome scores and chondral status at MRI of 10 patients with posterior medial meniscal root tear treated with the transtibial suture pull-out technique with two locking cinch sutures repair. Both IKDC and Lysholm score significantly increased at 5-year follow-up, and patients showed a worsening progression of medial femoral condyle and tibial plateau chondral disease. Laprade et al.[28] in their cadaveric study demonstrated that in situ pull-out suture repairs of posterior root tears and radial tears at 3 and 6 mm from the posterior root of lateral meniscus significantly improved the loading profiles of the lateral compartment, preventing the development of articular cartilage degeneration. Allaire et al.[31] demonstrated that repairing posterior root of medial meniscus was successful in restoring joint biomechanics.

3.5. MENISCAL EXTRUSION AS A PREDICTOR OF OSTEOARTHRITIS

Knee osteoarthritis is a major public health issue and causes chronic pain and disability among elderly patients in most of the developed countries. Epidemiologic studies have shown that knee OA affects over 250 million people worldwide, with a relevant impact on health care and society, and its incidence is showing a growing trend with the increasing life span.[69,70] The meniscal extrusion from the joint line represents an important risk factor in the development of OA,[11] due to joint space narrowing, loss of cartilage and increase in bone marrow lesions .[13,71] Indeed, ME can be used as an index correlated with the degree of pain and the clinical symptoms in knee OA.[72] Several studies indicate that pathological medial meniscus extrusion is a predictor for progression of knee OA.[73] Kawaguchi et al.[74] investigated medial ME in knee OA and showed an increased radial displacement by ultrasound with weight-bearing. Therefore, they reported a time-dependent close correlation between ME and the progression of OA. Svensson et al.[63] demonstrated that medial meniscal body extrusion is strongly associated with osteoarthritis features, particularly with bone marrow lesion, cartilage damage, and an increase in the KL score. Adams et al.[12] in a group of patients with knee OA showed that the association between ME and thinning of articular cartilage is higher in case of advanced disease (KL 4) rather than in patients with KL 1 or 2. Indeed, the early narrowing of the joint space has been described as a result of ME. In a study by Chiba et al.[75] the meniscal extrusion presented a strong positive association with medial joint space width in the group of patients with severe knee OA, while it showed a significant association with osteophytes formation in moderate knee OA. The authors reported also as 5.5 mm ME represents a threshold for rapid joint space narrowing progression in the severe knee OA. Lerer et al.[15] endorsed the rationale that ME leads to damage of articular cartilage, which contributes to the development of degenerative joint disease (DJD), as a progression of knee OA. In fact, they showed that 75% of the examined patients with significant DJD had > 3 mm medial ME. Van der Voet et al.[71] studied the relationship between baseline ME and the incidence of knee OA after 30 months in a group of overweight and obese women without knee OA at baseline. They showed that 28.8% of the knees with ME presented a progression to knee OA, while only 14.2% of the knees without extrusion had developed knee OA. Furthermore, the radiographic sign of knee OA and medial joint space narrowing was seen significantly more often in knees with ME. In a study by Driban et al.[10] it has been shown that 72% of knees with accelerated OA presented medial ME, while 28% had subchondral damage. Moreover, meniscal extrusion, meniscal tear and acute subchondral damage represent risk factors in the pathogenesis of early knee OA. Paletta et al.[76] in their study analyzed 6 cadaveric knees and they measured ME using ultrasound in different conditions. They demonstrated that detachment of the medial meniscotibial ligament increases ME from a mean of 1.5mm to a mean of 3.4mm, and that the repair of this ligament significantly reduces ME to a mean of 2.1mm. Dean et al.[77] described a new technique - recommended in case of a first repair failure of the posterior root of medial meniscus - for stabilizing the meniscal profile by reducing ME. They proved that greater stability in the meniscus should be a protective factor for the root reducing the risk of surgical failure.

4. DISCUSSION

Meniscal lesions represent the second most common intra-articular injury of the knee and are the most frequent case of orthopedic surgeries.[78,79] It has been shown that in the United States (US) the mean annual incidence of meniscal lesions ranges from 61 to 66 per 100.000 inhabitants[80] and most of them continued to be treated by meniscectomy. The peak incidence occurs at the age of 20-29 for both genders.[81] Meniscus root tears represent specific meniscal injuries, which have been highlighted within the last 5 years and have been proved to count for 10% to 21% of all meniscal tears, affecting almost 100,000 patients every year.[25] OA is identified by the World Health Organization as one of the four chronic musculoskeletal conditions that will continue to become more prevalent as the population ages,[82] and affects approximately 27 million adults in the US alone.[83] Prosthetic replacement is the inevitable consequence of the failure of conservative treatment for the OA. In 2009, knee arthroplasty became the fourteenth most common inpatient procedure in the US, being responsible for 22 hospital stays per 10,000 population. It is predicted that by the year 2030, there will be approximately 3.5 million primary TKAs each year in the US.[84] It is reasonable to assume that these trends in costs will continue to rise as the population ages and a greater number of individuals elect to have these surgical procedures.[85] As future prospects, a correct diagnosis and an early repair of meniscal lesions associated with meniscal extrusion can lead to a slowdown of the degenerative process, to better success of conservative or surgical treatments, and to less number of prosthetic replacements,

with significant economic benefits for the health system and increased quality of life for the patients.

5. CONCLUSIONS

In this study, we proved that meniscal extrusion represents an important risk factor for early knee OA. All the causes of ME have been explained, particularly the chronological relationship between meniscal extrusion and meniscal tears. We provided alternative theories of meniscal extrusion, such as meniscal fibers injury first. The phenomenon of aging has been described as a new concept in the etiology of ME. It has been shown the importance of dynamic extrusion of the menisci, which should not be considered pathological, but represents an important mechanism of dissipation of forces. As the main aim of the study, we stated all the main techniques and characteristics of the diagnostic process, as well as the current knowledge in the therapeutic field. Finally, we gave future perspectives for an early diagnosis of meniscal lesions in order to early treat them and to slow down the arthritic process.

AUTHOR CONTRIBUTIONS

Conceptualization, S.V. and R.P.; methodology, G.F.P.; formal analysis, P.Z. and S.V.; investigation, G.F.P and P.Z.; writing—original draft preparation, G.F.P. and P.Z.; writing—review and editing, S.V. and L.S.; supervision, E.F. and R.P.; project administration, R.P. All authors have read and agreed to the published version of the manuscript.

FUNDING

This research received no external funding.

INFORMED CONSENT STATEMENT

Not applicable.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

1. Madry H, Luyten FP, Facchini A. Biological aspects of early osteoarthritis. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(3):407-422. doi:10.1007/s00167-011-1705-8

2. Bloecker K, Wirth W, Guermazi A, et al. Relationship Between Medial Meniscal Extrusion and Cartilage Loss in Specific Femorotibial Subregions: Data From the Osteoarthritis Initiative. *Arthritis Care Res*. 2015;67(11):1545-1552. doi:10.1002/acr.22615

3. Hede A, Larsen E, Sandberg H. The long term outcome of open total and partial meniscectomy related to the quantity and site of the meniscus removed. *Int Orthop*. 1992;16(2):122-125. doi:10.1007/bf00180200

4. Krause WR, Pope MH, Johnson RJ, Wilder DG. Mechanical changes in the knee after meniscectomy. *J Bone Joint Surg Am*. 1976;58(5):599-604. doi:10.2106/00004623-197658050-00003

5. Jaureguito JW, Elliot JS, Lietner T, Dixon LB, Reider B. The effects of arthroscopic partial lateral meniscectomy in an otherwise normal knee: a retrospective review of functional, clinical, and radiographic results. *Arthrosc J Arthrosc Relat Surg*. 1995;11(1):29-36. doi:10.1016/0749-8063(95)90085-3

6. Rennie WJ, Finlay DBL. Meniscal Extrusion in Young Athletes: Associated Knee Joint Abnormalities. *Am J Roentgenol*. 2006;186(3):791-794. doi:10.2214/ajr.04.1181

7. Ahmed AM, Burke DL, Yu A. In-Vitro Measurement of Static Pressure Distribution in Synovial Joints—Part II: Retropatellar Surface. *J Biomech Eng*. 1983;105(3):226-236. doi:10.1115/1.3138410

8. Papalia R, Vasta S, Franceschi F, D'Adamio S, Maffulli N, Denaro V. Meniscal root tears: from basic science to ultimate surgery. *Br Med Bull*. 2013;106(1):91-115. doi:10.1093/bmb/ldt002

9. Crema MD, Roemer FW, Felson DT, et al. Factors Associated with Meniscal Extrusion in Knees with or at Risk for Osteoarthritis: The Multicenter Osteoarthritis Study. *Radiology*. 2012;264(2):494-503. doi:10.1148/radiol.12110986

10. Driban JB, Ward RJ, Eaton CB, et al. Meniscal extrusion or subchondral damage characterize incident accelerated osteoarthritis: Data from the osteoarthritis initiative. *Clin Anat*. 2015;28(6):792-799. doi:10.1002/ca.22590

11. Jones LD, Mellon SJ, Kruger N, Monk AP, Price AJ, Beard DJ. Medial meniscal extrusion: a validation study comparing different methods of assessment. *Knee Surg Sports Traumatol Arthrosc*. Published online April 21, 2017. doi:10.1007/s00167-017-4544-4

12. Adams JG, McaLindon T, Dimasi M, Carey J, Eustace S. Contribution of meniscal extrusion and cartilage loss to joint space narrowing in osteoarthritis. *Clin Radiol*. 1999;54(8):502-506. doi:10.1016/s0009-9260(99)90846-2

13. Hada S, Ishijima M, Kaneko H, et al. Association of medial meniscal extrusion with medial tibial osteophyte distance detected by T2 mapping MRI in patients with early-stage knee osteoarthritis. *Arthritis Res Ther*. 2017;19(1):201. doi:10.1186/s13075-017-1411-0

14. Costa CR, Morrison WB, Carrino JA. Medial Meniscus Extrusion on Knee MRI: Is Extent Associated with Severity of Degeneration or Type of Tear? *Am J Roentgenol*. 2004;183(1):17-23. doi:10.2214/ajr.183.1.1830017

15. Lerer DB, Umans HR, Hu MX, Jones MH. The role of meniscal root pathology and radial meniscal tear in medial meniscal extrusion. *Skeletal Radiol*. 2004;33(10). doi:10.1007/s00256-004-0761-2

16. Swamy N, Wadhwa V, Bajaj G, Chhabra A, Pandey T. Medial meniscal extrusion: Detection, evaluation and clinical implications. *Eur J Radiol*. 2018;102:115-124. doi:10.1016/j.ejrad.2018.03.007

17. Kenny C. Radial Displacement of the Medial Meniscus and Fairbank's Signs. *Clin Orthop*. 1997;339:163-173. doi:10.1097/00003086-199706000-00022

18. Muzaffar N, Kirmani O, Ahsan M, Ahmad D. Meniscal Extrusion in the Knee: Should only 3 mm Extrusion be Considered Significant? An Assessment by MRI and Arthroscopy. *Malays Orthop J*. 2015;9(2):17-20. doi:10.5704/moj.1507.013

19. Zhang F, Kumm J, Svensson F, Turkiewicz A, Frobell R, Englund M. Risk factors for meniscal body extrusion on MRI in subjects free of radiographic knee osteoarthritis: longitudinal data from the Osteoarthritis Initiative. *Osteoarthritis Cartilage*. 2016;24(5):801-806. doi:10.1016/j.joca.2015.12.003

20. Novaretti JV, Astur DC, Cavalcante ELB, Kaleka CC, Amaro JT, Cohen M. Preoperative Meniscal Extrusion Predicts Unsatisfactory Clinical Outcomes and Progression of Osteoarthritis after Isolated Partial Medial Meniscectomy: A 5-Year Follow-Up Study. *J Knee Surg*. 2020;35(04):393-400. doi:10.1055/s-0040-1715109

21. Zhang F, Bierma-Zeinstra SM, Oei EHG, Turkiewicz A, Englund M, Runhaar J. Factors associated with meniscal body extrusion on knee MRI in overweight and obese women. *Osteoarthritis Cartilage*. 2017;25(5):694-699. doi:10.1016/j.joca.2016.12.001

22. Ding C, Martel-Pelletier J, Pelletier JP, et al. Knee meniscal extrusion in a largely non-osteoarthritic cohort: association with greater loss of cartilage volume. *Arthritis Res Ther*. 2007;9(2):R21. doi:10.1186/ar2132

23. Kim SJ, Choi CH, Chun YM, et al. Relationship Between Preoperative Extrusion of the Medial Meniscus and Surgical Outcomes After Partial Meniscectomy. *Am J Sports Med*. 2017;45(8):1864-1871. doi:10.1177/0363546517697302

24. Forkel P, Reuter S, Sprenker F, et al. Different patterns of lateral meniscus root tears in ACL injuries: application of a differentiated classification system. *Knee Surg Sports Traumatol Arthrosc*. 2014;23(1):112-118. doi:10.1007/s00167-014-3467-6

25. Chahla J, LaPrade RF. Meniscal Root Tears. *Arthrosc J Arthrosc Relat Surg*. 2019;35(5):1304-1305. doi:10.1016/j.arthro.2019.02.010

26. Lee DW, Ha JK, Kim JG. Medial Meniscus Posterior Root Tear: A Comprehensive Review. *Knee Surg Relat Res*. 2014;26(3):125-134. doi:10.5792/ksrr.2014.26.3.125

27. Koenig JH, Ranawat AS, Umans HR, DiFelice GS. Meniscal Root Tears: Diagnosis and Treatment. *Arthrosc J Arthrosc Relat Surg*. 2009;25(9):1025-1032. doi:10.1016/j.arthro.2009.03.015

28. LaPrade CM, Jansson KS, Dornan G, Smith SD, Wijdicks CA, LaPrade RF. Altered Tibiofemoral Contact Mechanics Due to Lateral Meniscus Posterior Horn Root Avulsions and Radial Tears Can Be Restored with in Situ Pull-Out Suture Repairs. *J Bone Jt Surg*. 2014;96(6):471-479. doi:10.2106/jbjs.l.01252

29. Padalecki JR, Jansson KS, Smith SD, et al. Biomechanical Consequences of a Complete Radial Tear Adjacent to the Medial Meniscus Posterior Root Attachment Site: In Situ Pull-out Repair Restores Derangement of Joint Mechanics. *Am J Sports Med*. 2014;42(3):699-707. doi:10.1177/0363546513499314

30. Marzo JM, Gurske-DePerio J. Effects of Medial Meniscus Posterior Horn Avulsion and Repair on Tibiofemoral Contact Area and Peak Contact Pressure with Clinical Implications. *Am J Sports Med*. 2008;37(1):124-129. doi:10.1177/0363546508323254

31. Allaire R, Muriuki M, Gilbertson L, Harner CD. Biomechanical Consequences of a Tear of the Posterior Root of the Medial Meniscus: Similar to Total Meniscectomy. *J Bone Jt Surg-Am Vol*. 2008;90(9):1922-1931. doi:10.2106/jbjs.g.00748

32. Kim JG, Lee YS, Bae TS, et al. Tibiofemoral contact mechanics following posterior root of medial meniscus tear, repair, meniscectomy, and allograft transplantation. *Knee Surg Sports Traumatol Arthrosc*. 2012;21(9):2121-2125. doi:10.1007/s00167-012-2182-4

33. Pache S, Aman ZS, Kennedy M, et al. Meniscal Root Tears: Current Concepts Review. *Arch Bone Jt Surg*. 2018;6(4):250-259.

34. Minami T, Muneta T, Sekiya I, et al. Lateral meniscus posterior root tear contributes to anterolateral rotational instability and meniscus extrusion in anterior cruciate ligament-injured patients. *Knee Surg Sports Traumatol Arthrosc*. Published online May 8, 2017. doi:10.1007/s00167-017-4569-8

35. Kamatsuki Y, Furumatsu T, Fujii M, et al. Complete tear of the lateral meniscus posterior root is associated with meniscal extrusion in anterior cruciate ligament deficient knees: POSTERIOR ROOT TEAR CAUSES LATERAL MENISCAL EXTRUSION. *J Orthop Res*. 2018;36(7):1894-1900. doi:10.1002/jor.23861

36. Sung JH, Ha JK, Lee DW, Seo WY, Kim JG. Meniscal Extrusion and Spontaneous Osteonecrosis With Root Tear of Medial Meniscus: Comparison With Horizontal Tear. *Arthrosc J Arthrosc Relat Surg*. 2013;29(4):726-732. doi:10.1016/j.arthro.2012.11.016

37. Furumatsu T, Kodama Y, Kamatsuki Y, Hino T, Okazaki Y, Ozaki T. Meniscal Extrusion Progresses Shortly after the Medial Meniscus Posterior Root Tear. *Knee Surg Relat Res*. 2017;29(4):295-301. doi:10.5792/ksrr.17.027

38. Krych AJ, LaPrade MD, Hevesi M, et al. Investigating the Chronology of Meniscus Root Tears: Do Medial Meniscus Posterior Root Tears Cause Extrusion or the Other Way Around? *Orthop J Sports Med*. 2020;8(11):232596712096136. doi:10.1177/2325967120961368

39. Krych AJ, Bernard CD, Leland DP, et al. Isolated meniscus extrusion associated with meniscotibial ligament abnormality. *Knee Surg Sports Traumatol Arthrosc*. 2019;28(11):3599-3605. doi:10.1007/s00167-019-05612-1

40. Achtnich A, Petersen W, Willinger L, et al. Medial meniscus extrusion increases with age and BMI and is depending on different loading conditions. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(8):2282-2288. doi:10.1007/s00167-018-4885-7

41. Choi CJ, Choi YJ, Lee JJ, Choi CH. Magnetic Resonance Imaging Evidence of Meniscal Extrusion in Medial Meniscus Posterior Root Tear. *Arthrosc J Arthrosc Relat Surg*. 2010;26(12):1602-1606. doi:10.1016/j.arthro.2010.05.004

42. Karpinski K, Diermeier T, Willinger L, Imhoff AB, Achtnich A, Petersen W. No dynamic extrusion of the medial meniscus in ultrasound examination in patients with confirmed root tear lesion. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(10):3311-3317. doi:10.1007/s00167-018-5341-4

43. Petersen W, Tillmann B. Collagenous fibril texture of the human knee joint menisci. *Anat Embryol (Berl)*. 1998;197(4):317-324. doi:10.1007/s004290050141

44. Petersen W, Forkel P, Feucht MJ, Zantop T, Imhoff AB, Brucker PU. Posterior root tear of the medial and lateral meniscus. *Arch Orthop Trauma Surg*. 2014;134(2):237-255. doi:10.1007/s00402-013-1873-8

45. Tanamas S, Hanna FS, Cicuttini FM, Wluka AE, Berry P, Urquhart DM. Does knee malalignment increase the risk of development and progression of knee osteoarthritis? A systematic review. *Arthritis Rheum*. 2009;61(4):459-467. doi:10.1002/art.24336

46. Lefevre N, Naouri JF, Herman S, Gerometta A, Klouche S, Bohu Y. A Current Review of the Meniscus Imaging: Proposition of a Useful Tool for Its Radiologic Analysis. *Radiol Res Pract*. 2016;2016:1-25. doi:10.1155/2016/8329296

47. Chang A, Hochberg M, Song J, et al. Frequency of varus and valgus thrust and factors associated with thrust presence in persons with or at higher risk of developing knee osteoarthritis. *Arthritis Rheum*. 2010;62(5):1403-1411. doi:10.1002/art.27377

48. Erquicia J, Gelber PE, Cardona-Muñoz JI, Pelfort X, Tey M, Monllau JC. There is no relation between mild malalignment and meniscal extrusion in trauma emergency patients. *Injury*. 2012;43:S68-S72. doi:10.1016/s0020-1383(13)70183-9

49. Tsujii A, Nakamura N, Horibe S. Age-related changes in the knee meniscus. *The Knee*. 2017;24(6):1262-1270. doi:10.1016/j.knee.2017.08.001

50. Filippou G, Adinolfi A, Cimmino MA, et al. Diagnostic accuracy of ultrasound, conventional radiography and synovial fluid analysis in the diagnosis of calcium pyrophosphate dihydrate crystal deposition disease. *Clin Exp Rheumatol*. 2016;34(2):254-260.

51. Razek AAKA, Fouda NS, Elmetwaley N, Elbogdady E. Sonography of the knee joint. *J Ultrasound*. 2009;12(2):53-60. doi:10.1016/j.jus.2009.03.002

52. Nogueira-Barbosa MH, Gregio-Junior E, Lorenzato MM, et al. Ultrasound Assessment of Medial Meniscal Extrusion: A Validation Study Using MRI as Reference Standard. *Am J Roentgenol*. 2015;204(3):584-588. doi:10.2214/ajr.14.12522

53. Mureşan S, Mureşan M, Voidăzan S, Neagoe R. The accuracy of musculoskeletal ultrasound examination for the exploration of meniscus injuries in athletes. *J Sports Med Phys Fitness*. 2017;57(5). doi:10.23736/s0022-4707.17.06132-1

54. Verdonk P, Depaepe Y, Desmyter S, et al. Normal and transplanted lateral knee menisci: evaluation of extrusion using magnetic resonance imaging and ultrasound. *Knee Surg Sports Traumatol Arthrosc*. 2004;12(5):411-419. doi:10.1007/s00167-004-0500-1

55. Ijaz Khan H, Chou L, Aitken D, et al. Correlation Between Changes in Global Knee Structures Assessed by Magnetic Resonance Imaging and Radiographic Osteoarthritis Changes Over Ten Years in a Midlife Cohort: MRI and Radiographic Knee Structures Assessment Correlation. *Arthritis Care Res*. 2016;68(7):958-964. doi:10.1002/acr.22778

56. Roemer FW, Kwoh CK, Hannon MJ, et al. What Comes First? Multitissue Involvement Leading to Radiographic Osteoarthritis: Magnetic Resonance Imaging-Based Trajectory Analysis Over Four Years in the Osteoarthritis Initiative. *Arthritis Rheumatol*. 2015;67(8):2085-2096. doi:10.1002/art.39176

57. Patel R, Eltgroth M, Souza RB, et al. Loaded versus unloaded magnetic resonance imaging (MRI) of the knee: Effect on meniscus extrusion in healthy volunteers and patients with osteoarthritis. *Eur J Radiol Open*. 2016;3:100-107. doi:10.1016/j.ejro.2016.05.002

58. Sharma L, Nevitt M, Hochberg M, et al. Clinical significance of worsening versus stable preradiographic MRI lesions in a cohort study of persons at higher risk for knee osteoarthritis. *Ann Rheum Dis*. 2016;75(9):1630-1636. doi:10.1136/annrheumdis-2015-208129

59. Hunter DJ, Guermazi A, Lo GH, et al. Evolution of semi-quantitative whole joint assessment of knee OA: MOAKS (MRI Osteoarthritis Knee Score). *Osteoarthritis Cartilage*. 2011;19(8):990-1002. doi:10.1016/j.joca.2011.05.004

60. Brody JM, Lin HM, Hulstyn MJ, Tung GA. Lateral Meniscus Root Tear and Meniscus Extrusion with Anterior Cruciate Ligament Tear. *Radiology*. 2006;239(3):805-810. doi:10.1148/radiol.2393050559

61. Muhle C, Ahn JM, Dieke C. Diagnosis of ACL and meniscal injuries: MR imaging of knee flexion versus extension compared to arthroscopy. *SpringerPlus*. 2013;2(1):213. doi:10.1186/2193-1801-2-213

62. Diermeier T, Beitzel K, Bachmann L, et al. Mountain ultramarathon results in temporary meniscus extrusion in healthy athletes. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(8):2691-2697. doi:10.1007/s00167-018-5303-x

63. Svensson F, Felson DT, Turkiewicz A, et al. Scrutinizing the cut-off for "pathological" meniscal body extrusion on knee MRI. *Eur Radiol*. 2019;29(5):2616-2623. doi:10.1007/s00330-018-5914-0

64. Kim DH, Lee GC, Kim HH, Cha DH. Correlation between meniscal extrusion and symptom duration, alignment, and arthritic changes in medial meniscus posterior root tear: research article. *Knee Surg Relat Res*. 2020;32(1):2. doi:10.1186/s43019-019-0019-x

65. Furumatsu T, Kamatsuki Y, Fujii M, et al. Medial meniscus extrusion correlates with disease duration of the sudden symptomatic medial meniscus posterior root tear. *Orthop Traumatol Surg Res*. 2017;103(8):1179-1182. doi:10.1016/j.otsr.2017.07.022

66. Krych AJ, Nauert RFI, Song BM, et al. Association Between Transtibial Meniscus Root Repair and Rate of Meniscal Healing and Extrusion on Postoperative Magnetic Resonance Imaging: A Prospective Multicenter Study. *Orthop J Sports Med*. 2021;9(8):232596712110237. doi:10.1177/23259671211023774

67. Moon HS, Choi CH, Jung M, Lee DY, Hong SP, Kim SH. Early Surgical Repair of Medial Meniscus Posterior Root Tear Minimizes the Progression of Meniscal Extrusion: 2-Year Follow-up of Clinical and Radiographic Parameters After Arthroscopic Transtibial Pull-out Repair. *Am J Sports Med*. 2020;48(11):2692-2702. doi:10.1177/0363546520940715

68. Kaplan DJ, Bloom D, Alaia EF, et al. ICRS scores worsen between 2-year short term and 5-year mid-term follow-up after transtibial medial meniscus root repair despite maintained functional outcomes. *Knee Surg Sports Traumatol Arthrosc*. 2021;30(7):2235-2243. doi:10.1007/s00167-021-06747-w

69. Ondrésik M, Azevedo Maia FR, da Silva Morais A, et al. Management of knee osteoarthritis. Current status and future trends: Management of Knee Osteoarthritis. *Biotechnol Bioeng*. 2017;114(4):717-739. doi:10.1002/bit.26182

70. Zhang Y, Jordan JM. Epidemiology of Osteoarthritis. *Clin Geriatr Med*. 2010;26(3):355-369. doi:10.1016/j.cger.2010.03.001

71. van der Voet JA, Runhaar J, van der Plas P, Vroegindeweij D, Oei EH, Bierma-Zeinstra SMA. Baseline meniscal extrusion associated with incident knee osteoarthritis after 30 months in overweight and obese women. *Osteoarthritis Cartilage*. 2017;25(8):1299-1303. doi:10.1016/j.joca.2017.03.014

72. Kijima H, Miyakoshi N, Kasukawa Y, et al. Cut-Off Value of Medial Meniscal Extrusion for Knee Pain. *Adv Orthop*. 2017;2017:1-4. doi:10.1155/2017/6793026

73. Papalia R, Papalia G, Russo F, et al. Meniscal extrusion as booster of osteoarthritis. *J Biol Regul Homeost Agents*. 2017;31(4 Suppl 2):33-44.

74. Kawaguchi K, Enokida M, Otsuki R, Teshima R. Ultrasonographic evaluation of medial radial displacement of the medial meniscus in knee osteoarthritis. *Arthritis Rheum*. 2012;64(1):173-180. doi:10.1002/art.33319

75. Chiba D, Maeda S, Sasaki E, et al. Meniscal extrusion seen on ultrasonography affects the development of radiographic knee osteoarthritis: a 3-year prospective cohort study. *Clin Rheumatol*. 2017;36(11):2557-2564. doi:10.1007/s10067-017-3803-6

76. Paletta GAJ, Crane DM, Konicek J, et al. Surgical Treatment of Meniscal Extrusion: A Biomechanical Study on the Role of the Medial Meniscotibial Ligaments With Early Clinical Validation. *Orthop J Sports Med*. 2020;8(7):232596712093667. doi:10.1177/2325967120936672

77. Dean RS, DePhillipo NN, Monson JK, LaPrade RF. Peripheral Stabilization Suture to Address Meniscal Extrusion in a Revision Meniscal Root Repair: Surgical Technique and Rehabilitation Protocol. *Arthrosc Tech*. 2020;9(8):e1211-e1218. doi:10.1016/j.eats.2020.04.022

78. Fukubayashi T, Kurosawa H. The Contact Area and Pressure Distribution Pattern of the Knee:*A Study of Normal and Osteoarthrotic Knee Joints*. *Acta Orthop Scand*. 1980;51(1-6):871-879. doi:10.3109/17453678008990887

79. Salata MJ, Gibbs AE, Sekiya JK. A Systematic Review of Clinical Outcomes in Patients Undergoing Meniscectomy. *Am J Sports Med*. 2010;38(9):1907-1916. doi:10.1177/0363546510370196

80. Logerstedt DS, Scalzitti DA, Bennell KL, et al. Knee Pain and Mobility Impairments: Meniscal and Articular Cartilage Lesions Revision 2018. *J Orthop Sports Phys Ther*. 2018;48(2):A1-A50. doi:10.2519/jospt.2018.0301

81. GarrettJr. WE. American Board of Orthopaedic Surgery Practice of the Orthopaedic Surgeon: Part-II, Certification Examination Case Mix. *J Bone Jt Surg Am*. 2006;88(3):660. doi:10.2106/jbjs.e.01208

82. Woolf AD, Pfleger B. Burden of major musculoskeletal conditions. *Bull World Health Organ*. 2003;81(9):646-656.

83. Lawrence RC, Felson DT, Helmick CG, et al. Estimates of the prevalence of arthritis and other rheumatic conditions in the United States: Part II. *Arthritis Rheum*. 2007;58(1):26-35. doi:10.1002/art.23176

84. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of Primary and Revision Hip and Knee Arthroplasty in the United States from 2005 to 2030. *J Bone Jt Surg*. 2007;89(4):780-785. doi:10.2106/jbjs.f.00222

85. Masaracchio M, Hanney WJ, Liu X, Kolber M, Kirker K. Timing of rehabilitation on length of stay and cost in patients with hip or knee joint arthroplasty: A systematic review with meta-analysis. *PLoS ONE*. 2017;12(6):e0178295. doi:10.1371/journal.pone.0178295