Websites:
http://www.sciencepub.net/nature
http://www.sciencepub.net

Emails:
naturesciencej@gmail.com
editor@sciencepub.net

Nature and Science

MARSLAND PRESS
Multidisciplinary Academic Journal Publisher

Artificial Knee Menisci: Indications, Types and Outcomes

Waheeb S. Aggad*, Gamal S. Abd El-Aziz, Hamid A. Saleh

Department of Anatomy, Faculty of Medicine, King Abdulaziz University, Jeddah, KSA
*e-mail: dr.aggad@hotmail.com

Abstract: In the knee joint, the menisci are crucial functional units, which serve as lubricating and shock-absorbent structures during different movements, as well as providing stability and load distribution which is very important inside the knee. The most common knee injury is meniscal tears which is ailments and continue to rise due to ageing and several sport activities. The most of these injuries are usually subjected to conservative management; however quite a few of these cases are non-reparable lesions and generally require a partial or even total meniscectomy. However, most of the patients gain from post-meniscectomy relief of pain and functional improvement, some still to suffer from severe symptoms, meniscal substitution procedures or replacement options are mandatory. These options ranged from the use of autologous and allografting to the implantation of an artificial synthetic meniscal substitutes in recent years, which is only recommended for the very severely damaged menisci. In terms of potential polymeric biomaterial combinations, there have been recent developments in meniscal tissue engineering and regenerative medicine., resulting in innovative strategies. **The goal of this review** is to give comprehensive information on the indications, types, and outcomes of meniscal substitutes, with a special emphasis on tissue engineering leveraging new technological breakthroughs in scaffolds for meniscus reconstruction and regeneration. **Outcomes:** Over the last few decades, increasing clinical data and great scientific efforts have raised awareness which is the significant of the menisci into the knee joint. However, leading to the development of the replacing the knee meniscus therapy alternatives for irreversible meniscal lesions. The part of materials which resembles the physical and mechanical properties of native menisci, as well as the preservation of the meniscal microenvironment, has resulted from advances in tissue engineering. Nonetheless, all research on the development and testing of meniscus replacements provides a wealth of knowledge that may be applied to constructing the ideal meniscal substitute with the purpose of improving post-meniscectomy syndrome patients' outcomes.

[Waheeb S. Aggad, Gamal S. Abd El-Aziz, Hamid A. Saleh. **Artificial Knee Menisci: Indications, Types and Outcomes**.Nat Sci 2022;20(2);45-51]. ISSN 1545-0740 (print); ISSN 2375-7167 (online). http://www.sciencepub.net/nature. 5. doi:10.7537/marsnsj200222.05.

Keywords: Tissue engineering, Knee Meniscus, Substitute, Scaffold, Biomaterial, 3-D printing

Introduction

Meniscal lesions are the most prevalent intra-articular knee injuries in humans, and they are also the most common reason for knee surgery [1]. Based on reliable data, advanced age, male gender at work kneeling, squatting, and stair climbing have all been identified as risk factors for degenerative tears. Traumatic meniscal injuries are more common in the younger population (for example, sports), while degenerative tears have also been reported in the older population. Osteoarthritis of the knee has known of risk factors [2-7].

To treat meniscal injuries, a variety of therapeutic techniques have been developed over the last few decades. Several aspects related to the patients (general health status, activity, level, age, lifestyle) and those associated to the lesions should be considered when deciding whether to use non-surgical or operative treatments to treat meniscal lesions (type, location, etiology, associated lesions, and tissue quality). In general, meniscus repair is performed to fix problems when the tears aren't too complicated, and the meniscal tissues haven't degraded too much [8,9]. Partial or complete meniscectomy is the best or only therapeutic option when meniscal injury is persistent [10,11].

Although meniscal excision may result in a fast alleviation of clinical manifestations, a small patients' percentage experience lingering discomfort after time of condition is known as "post-meniscectomy syndrome." In addition, due to higher peak loads and misalignments on the articular cartilage, multiple studies have shown an increased rate of knee osteoarthritis (OA) and worse clinical and functional results after meniscectomy [12-14].

As a result, various efforts have been made to produce meniscal substitutes, which could help restore knee biomechanics, improve clinical results, and prevent the beginning of knee OA [15, 16]. Despite substantial progress in this area, the fundamental challenge remains the development of a bio-functional and patient-specific substitute that can restore knee mechanics and function like a native meniscus. The construction of such a substitute is difficult due to the meniscus's distinct and complex structure. Synthetic and natural materials for meniscal replacement have been described with varying results in the search for the ultimate meniscal substitute [17,18].

The many attempts to replace the missing tissue can be divided into three types. The first is the use of natural tissues, such as autogenous tissues [19] or transplants [20, 21]. The second strategy is to replace the lost meniscal tissue with tissue-engineering scaffolds, which could include cells and particular cytokines [22]. Finally, prosthetic implants would have a place [23-25].

To incorporate these changing therapies into clinical practice and avoid the severe consequences of losing meniscal tissue, a thorough understanding of the various techniques to meniscal replacement is essential [18]. Therefore, the goal of this review is to give wide-ranged information on the indications, types, and outcomes of meniscal substitutes, with a special emphasis on tissue engineering leveraging new technological breakthroughs in scaffolds for meniscus reconstruction and regeneration.

Autologous Substitutes (Autografts) and Allogenic Substitutes (Allografts)

Autologous Substitutes

Allograft tissue comes from a donor, whereas autograft tissue comes from the patient. Fat pad, cartilage, periosteum, and perichondrium are all autologous tissues used in meniscal repair [26,27]. The autograft's biomechanical properties were far inferior to the original meniscus, despite its histological, morphological, and histological similarities to the native meniscus. As a result, no regular therapeutic use has been established [28].

Allogenic Substitutes

A human donor meniscus is used in meniscal allograft transplantation (MAT), which also serves as a scaffold and best mimics the morphological and biomechanical characteristics of the missing meniscal tissue. For symptomatic, meniscus-deficient patients, MAT may be a viable option. Who have undergone subtotal or total meniscectomy with the main goal to relief pain, restore meniscal function and prevent OA and a subsequent improved quality of life [29-31].

However, it was reported that not most of patients with deficient menisci are candidates for MAT [32,33]. Patients under the age of 50 who have a primary complaint of pain that is restricting their activities are great candidates, as multiple studies have shown satisfactory outcomes with MAT in young patients [34, 35], athletes [36] and advanced cartilage injury [37].

Although MAT is a common, safe, and reliable procedure for total meniscus replacement, it has drawbacks, including the close to giver supply, which is the requirement to proper graft size and attachment, the surgery's complexity, the prohibition of transmitted disease, the chance of an immune impairing recovery, and so on, as well as the occurrence of articular degeneration after transplantation, all of which limit the number of meniscal transplants [38-40].

Artificial Substitutes

Emerging technologies, such as biomaterials, cellular engineering, and 3D printing, have increased the number of options for replacing a damaged meniscus in recent decades [41]. The biological and biomechanical features of an ideal meniscus replacement should be identical to those of the native meniscus. Importantly The structure, function, and anisotropic qualities of the meniscus should all be restored with a long-term functional meniscus replacement [42].

Meniscal Scaffolds-Based Substitutes

To preserve joints and slow the course of osteoarthritis, artificial scaffold-based meniscal replacements should be used in conjunction with articular cartilage. Furthermore, optimal meniscus alteration must be resorbing or decay delayed sufficiently to permit the vascular of tissue's, cellular, extracellular matrix, structural to develop and regenerate. The meniscal scaffold must be safe for the joint as it deteriorates while offering maximum mechanical performance (destruction and strength) and macromolecule and nutrient permeability. Finally, the ideal scaffold must be easily available for clinical usage at the point of care, minimally invasive, and technically simple to implant [43-45].

Synthetic and natural materials are all examples of scaffolds for meniscal replacement [46]. Natural scaffolds have a significant advantage in scaffold fabrication because they are easily modifiable and may be adjusted biomechanically and biologically during the manufacturing process, which is permit the engineered construct to imitate tissues for a given application. Thus, a biocompatible and biodegradable natural polymeric scaffold can be created to allow for the flow of metabolites and nutrients, offer mechanical support, have adequate porosity, and provide an aqueous environment for cellular encapsulation, tissue creation and proliferation [47-49].

Collagens

Collagen is a naturally occurring matrix polymer with three polypeptide chains that is the most common extracellular matrix protein. The meniscus is mostly made up of type I collagen, which contributes greatly to the normal matrix biomechanical capabilities and composition of the meniscus. Because they convert vertical compressive pressures into circular hoop stress, longitudinal collagen fibers are essential for optimal meniscal function and chondroprotection [50].

Hydrogels

It is feasible to vary mechanical features and tissue in-growth rates by changing the hydrogel of the linking the part of chemical of the density and crosslinking chemistry of the scaffolds [51]. Hydrogels can offer cells with a physiologically acceptable environment that promotes extracellular matrix synthesis and the cell proliferation, migration, and because they have structural and the functional identical to natural extracellular matrix [52,53]. Under a range of environmental variables, such as temperature, pH, electric field, and ultrasound, hydrogels contain chemical diversity and salt [45].

Synthetic Scaffolds for Meniscus Replacement

Tissue engineering has employed synthetic polymer scaffolds in several ways. Synthetic polymers have the benefit of allowing the creation of custom-designed biomedical implants and devices with precise structure, and the properties of biomechanical. They can be adjusted to a certain cellular structural, and cellular environment. For example. The low cell-adhesive qualities of synthetic polymers, as well as the possibility of a foreign body reaction following implantation or material breakdown, are potential drawbacks [54].

Meniscal Scaffolds in Clinical Use

The natural Collagen Meniscus Implant (CMI) and the synthetic porous polyurethane-based scaffold are a couple of artificial, scaffold based, and meniscal biocompatible alternatives that are commercially available in clinical practice for meniscal replacement [55]. The collagen type 1 fiber is extracted from bovine Achilles' tendons make up the collagen meniscus implant (CMI) [42]. Actifit is the second artificial meniscal alternative, and it was just recently created. Polycaprolactone (80%) and polyurethane (the remaining 20%) make up the material (the other 20 percent). 20% of the total [56,57].

The indications and surgical techniques for these two implants are similar. These procedures can be performed arthroscopically, as previously stated [22]. Polyurethane-based scaffolds and CMI have recently been discovered to provide good mid-term and long-term clinical results in terms of therapeutic effectiveness [58,59]. Clinical failure is known as scaffold which is concerned infections, mechanical defect, persistent synovitis, or the need for reoperation in as many as 8% and 32% of CMI and Actifit patients. [44,60].

Scaffolds and Cell Seeding

Scaffolds seeded with a certain cell type based on the need can be utilized to regenerate artificial tissue in the same way as natural cells can. There are several types of cells that can be used to regenerate the meniscus. Autologous cells, allogeneic cells, and stem cells, or a mix of the three [45]. A synthetic polymeric scaffold [48], tissue derived materials, or hybrid / composites of all the above can be used to replace the meniscus tissue [61]. The menisci cells are made up of fibroblasts and chondrocytes. Synthetic scaffolds might have downsides including high refuced, unexpected deterioration, or increase the swelling, and each scaffold transplant must undergo comprehensive testing before being selected for implantation [62].

Scaffold Made of Textiles or Fibers

It is having an increasing surface area: volume ratio, a highly interconnected porous structure, the ability to create a three-dimensional structure, and ease of fabrication over other scaffold structures. However, one of the disadvantages of textile-based scaffolds is structural stability, which can be solved by fiber-reinforced composites [63].

Different spacing between fibers was used to investigate fiber-matrix interfacial characteristics and mechanical performance. The scaffold had inherent meniscus-like tensile properties and could create meniscus-like shape. More study is needed, according to the authors, to better understand the numerous factors that influence the formation of functional meniscus [64,65].

Tissue Engineering

Tissue engineering is a technique that combines a mix of cells, bioactive agent scaffolds, and biophysical stimuli to encourage the growth of neo-tissues to construct biological replacements that restore, maintain, or improve tissue function [66-68]. Tissue engineering of the knee meniscus could be a potential therapy option for meniscal problems, according to a vast number of studies [69]. However, there are certain drawbacks to tissue engineering with allografts and autografts, such as the risk of infection, rejection, availability, cost, and preservation. As a result, the focus of tissue engineering research is on scaffolds made of synthetic or natural materials. Production materials based on scaffolds are increasingly adaptable to outlook tissue engineering approaches due to their ease of availability, processability, and ability to customize scaffold characteristics and structure [70,71].

Control over custom-made shape designs, structures made using various manufacturing techniques, flexibility in designing scaffold properties, easy availability, reproducibility, and repeatability are all advantages of scaffold-based tissue engineering for knee meniscus reconstruction and regeneration through other methods. Despite the tissue's inherent activities, many published tissues engineering studies ignore the mechanical properties of meniscal constructs or repair tissue, which is a critical outcome metric. The absence of consistent and objective outcome assessments throughout trials to determine the efficacy of different meniscal scaffolds, as well as agreement on success criteria and benchmarks, are major hurdles [18,72].

MSCs (or fibrochondrocytes/chondrocytes) are usually directed to the injured area after being implanted in a cell carrier for example scaffold and hydrogel. Tear site, the cell carrier can release bioactive compounds and/or provide structural support to the cells and subsequent neotissue. In two different experiments, MSCs encapsulated in a thermosensitive matrix [73] or photocrosslinkable MSCs were injected [74]. Injecting a hydrogel into a rabbit or goat meniscal tear improved healing, especially when pro-chondrogenic TGF- isoforms were also infused.

3D Printing

3-D printed meniscal scaffolds are one of the most promising developing medical technologies in the twenty-first century for meniscus replacement. These three-dimensional scaffolds may be recreated to fit the geometries of individual patients and restore the meniscus' overall shape. Furthermore, 3D-printed scaffolds could be used to produce artificial implants, which could be used in clinical practice soon [75,76], According to the study, meniscus dECM hydrogel was added to a printed polycaprolactone (PCL) scaffold in the shape of a meniscus in three dimensions (3D). In terms of chondrogenic differentiation, cell proliferation, collagen, glycosaminoglycan and production, and mechanical properties, the hybrid-scaffolds outperformed the PCL scaffold without dECM when seeded with MFCs.

Meniscus Prostheses

Meniscal replacement can also be done with artificial prostheses, which are non-degradable, anatomically [77,78] and non-anatomically [64] fashioned artificial meniscal substitutes (prostheses). However, because of the intricate biomechanical properties of the meniscus, designing prosthetic meniscus devices is extremely difficult. It's also uncertain whether it needs to be attached to the capsule and bone. Novel biomaterials are currently undergoing extensive research to see if they can be used to create typical meniscus surface properties [24,25].

Conclusion

There are various hurdles to overcome in producing a human meniscal substitute, but the ambition to create an adequately sized meniscal substitute with mechanical properties and functions that are like those seen in humans is a common goal. Currently, none of the available methods can restore the native meniscus' identical morphology, biochemical content, or cellular phenotypes to match these qualities for each individual patient. Clearly, each of these approaches necessitates extensive preclinical research and, eventually, human clinical trials. To that aim, the amount of time it takes to make the device, the materials employed, the adaptability of the processes used, and, finally, the cost of producing a functional meniscal substitute must all be carefully evaluated. **Finally,** a balance of manufacturing complexity, biosafety, and product efficacy will be required to assess whether the method is appropriate for developing a novel patient-specific meniscal device for the treatment of damaged menisci.

References

[1]. Mather R.C., Garrett W.E., Cole B.J. Hussey K., Bolognesi M.P., Lassiter T. and Orlando L.A. (2015). Cost-effectiveness analysis of the diagnosis of meniscus tears. Am J Sports Med, 43 (1):128–137.

[2]. Nguyen J.C., De Smet A.A., Graf B.K. and Rosas H.G. (2014). MR imaging-based diagnosis and classification of meniscal tears. Radiographics, 34 (4):981e99.

[3]. Vaquero J. and Forriol F. (2016). Meniscus tear surgery and meniscus replacement. Muscles Ligaments Tendons J, 6:71–89.

[4]. Beaufils P., Becker R., Kopf S., Matthieu O. and Pujol N. (2017). The knee meniscus: management of traumatic tears and degenerative lesions. EFORT Open Rev, 2:195–203.

[5]. Melrose J., Fuller E.S. and Little C.B. (2017). The biology of meniscal pathology in osteoarthritis and its contribution to joint disease: beyond simple mechanics. Connect Tissue Res, 58(3e4):282e94.

[6]. Tsujii A., Nakamura N. and Horibe S. (2017). Age-related changes in the knee meniscus. Knee, 24: 1262–1270.

[7]. Kopf S., Beaufls P., Hirschmann M.T., Rotigliano N., Ollivier M., Pereira H., Verdonk R., Darabos N., Ntagiopoulos P., Dejour D., Seil R. and Becker R. (2020). Management of traumatic meniscus tears: the 2019 ESSKA meniscus consensus. Knee Surg Sports Traumatol Arthrosc, 28:1177–1194.

[8]. Yim J.H., Seon J.K., Song E.K., Choi J.I., Kim M.C., Lee K.B. and Seo H.Y. (2013). A comparative study of meniscectomy and nonoperative treatment for degenerative horizontal tears of the medial meniscus. Am J Sports Med, 41 (7):1565–1570.

[9]. Mordecai S.C., Al-Hadithy N., Ware H.E. and Gupte C.M. (2014). Treatment of meniscal tears: an evidence-based approach. World J Orthop, 5(3):233–241.

[10]. Parker B.R., Hurwitz S., Spang J., Creighton R. and Kamath G. (2016). Surgical trends in the treatment of meniscal tears: analysis of data from the American Board of Orthopaedic Surgery Certification Examination Database. Am J Sports Med, 44:1717–1723.

[11]. Espejo-Reina A., Aguilera J., Espejo-Reina M.J., Espejo-Reina M.P. and Espejo-Baena A. (2019). One-third of meniscal tears are repairable: an epidemiological study evaluating meniscal tear

patterns in stable and unstable knees. Arthroscopy, 35:857–863.
[12]. Persson F., Turkiewicz A., Bergkvist D., Neuman P. and Englund M. (2018). The risk of symptomatic knee osteoarthritis after arthroscopic meniscus repair *vs* partial meniscectomy vs the general population. Osteoarthr Cartil, 26:195–201.
[13]. Drobnič M., Ercin E., Gamelas J., Papacostas E.T., Slynarski K., Zdanowicz U., Spalding T. and Verdonk P. (2019). Treatment options for the symptomatic post-meniscectomy knee. Knee Surg Sports Traumatol Arthrosc, 27 (6):1817–1824.
[14]. Novaretti J.V., Lian J., Patel N.K., Chan C.K., Cohen M., Musahl V. and Debski R.E. (2020). Partial lateral Meniscectomy affects knee stability even in anterior cruciate ligament-intact knees. J Bone Joint Surg Am. 102 (7):567–573.
[15]. Gelber P.E., Verdonk P., Getgood A.M. and Monllau J.C. (2017).Meniscal transplantation: state of the art. JISAKOS, 2:339–349.
[16]. Barnds B., Morris B., Mullen S., Schroeppel J.P., Tarakemeh A. and Vopat B.G. (2019). Increased rates of knee arthroplasty and cost of patients with meniscal tears treated with arthroscopic partial meniscectomy versus non-operative management. Knee Surg Sports Traumatol Arthrosc 27:2316–2321.
[17]. Feeley B.T. and Lau B.C. (2018). Biomechanis and clinical outcoms of partial meniscectomy. J Am Acad Orthop Surg. 26:853-863.
[18]. Winkler P.W., Rothrauff B.B., Buerba R.A., Shah N., Zaffagnini S., Alexander P. and Musah V. (2020). Meniscal substitution, a developing and long-awaited demand. Journal of Experimental Orthopaedics, 7:55.
[19]. Johnson L.L. and Feagin J.A. (2000). Autogenous tendon graft substitution for absent knee joint meniscus: a pilot study. Arthroscopy, 16:191–196.
[20]. Kim J.M., Lee B.S., Kim K.H., Kim K.A. and Bin S.I. (2012). Results of meniscus allograft transplantation using bone fixation: 110 cases with objective evaluation. Am J Sports Med, 40:1027–1034.
[21]. McCormick F., Harris J.D., Abrams G.D., Hussey K.E., Wilson H., Frank R., Gupta A.K. and Bach Jr B.R. (2014). Survival and reoperation rates after meniscal allograft transplantation: analysis of failures for 172 consecutive transplants at a minimum 2-year follow-up. Am J Sports Med, 42 (4):892–897.
[22]. Verdonk R., Verdonk P., Huysse W., Forsyth R. and Heinrichs E.L. (2011). Tissue ingrowth after implantation of a novel, biodegradable polyurethane scaffold for treatment of partial meniscal lesions. Am J Sports Med, 39:774–782 .
[23]. Filardo G., Andriolo L., Kon E., de Caro F. and Marcacci M. (2015). Meniscal scaffolds: results and indications. A systematic literature reviews. Int Orthop, 39:35–46.
[24]. Murakami T., Otsuki S., Nakagawa K., Okamoto Y., Inoue T., Sakamoto Y., Sato H., Neo M. (2017). Establishment of novel meniscal scaffold structures using polyglycolic and poly-L-lactic acids. J Biomater Appl, 32 (2): 150–161.
[25]. Zhang Z.Z., Wang S.J., Zhang J.Y., Jiang W.B., Huang A.B., Qi Y.S., Ding J.X., Chen X.S. Jiang D. and Yu J.K. (2017). 3D-Printed Poly (ε-caprolactone) scaffold augmented with mesenchymal stem cells for total meniscal substitution: A 12- and 24-week animal study in a rabbit model. Am J Sports Med, 45(7):1497–511.
[26]. Kohn D., Rudert M., Wirth C.J., Plitz W., Reiss G. and Maschek H. (1997). Medial meniscus replacement by a fat pad autograft: An experimental study in sheep. Inter Orthopaed, (SICOT), 21: 232–238.
[27]. Bruns J., Kahrs J., Kampen J., Behrens P. and Plitz W. (1998). Autologous perichondral tissue for meniscal replacement. J Bone Joint Surg Br, 80:918–923.
[28]. Liu C., Toma I.C., Mastrogiacomo M., Krettek C., Von Lewinski G. and Jagodzinski M. . (2013). Meniscus reconstruction: today's achievements and premises for the future. Arch Orthop Trauma Surg, 133(1); 95–109.
[29]. Rosso F., Bisicchia S., Bonasia D.E. and Amendola A. (2015). Meniscal allograft transplantation: a systematic review. Am J Sports Med, 43:998–1007.
[30]. Bin S.I., Nha K.W., Cheong J.Y. and Shin Y.S. (2018). Midterm and long-term results of medial versus lateral meniscal allograft transplantation: a meta-analysis. Am J Sports Med, 46:1243–1250.
[31]. Figueroa F., Figueroa D., Calvo R., Vaisman A. and Espregueira M.J. (2019). Meniscus allograft transplantation: indications, techniques, and outcomes. EFORT Open Rev, 4:115–120.
[32]. Verdonk R., Almqvist K. and Verdonk P. (2015). Meniscal allografts: indications and results. In: Doral MN, Karlsson J, eds. Sports Injuries: Prevention, Diagnosis, Treatment and Rehabilitation. 2nd ed. Springer: Verlag Berlin Heidelberg, 1183–1190.
[33]. Verdonk R., Madry H., Shabshin N., Dirisamer F., Peretti G.M., Pujol N., Spslding T., Verdonk P., Seil R., Condello V., Matteo B.D., Zellnr J. and Angele P. (2016). The role of meniscal tissue in joint protection in early osteoarthritis. Knee Surg Sports Traumatol Arthrosc, 24(6):1763-1774.
[34]. Riboh J.C., Tilton A.K., Cvetanovich G.L, Campbell K.A. and Brian J.C. (2016). Meniscal

allograft transplantation in the adolescent population. Arthroscopy, 32 (6):1133–1140.

[35]. Tuca M., Luderowski E. and Rodeo S. (2016). Meniscal transplant in children. Curr Opin Pediatr, 28:47–54.

[36]. Alentorn-Geli E., Vázquez R.S., Díaz P.Á., Cusco X. and Cugat R. (2010). Arthroscopic meniscal transplants in soccer players: outcomes at 2- to 5-year follow-up. Clin J Sport Med, 20 (5):340–343.

[37]. Getgood A., LaPrade R.F., Verdonk P., Gersoff W., Cole B., Spalding T. and IMREF group (2016). International Meniscus Reconstruction Experts Forum (IMREF) 2015 Consensus Statement on the Practice of Meniscal Allograft Transplantation. Am J Sports Med, 45 (5):1195-1205.

[38]. Lee S.R., Kim J.G. and Nam S.W. (2012). The tips and pitfalls of meniscus allograft transplantation. Knee Surg. Relat Res, 24: 137-145.

[39]. Dean C.S., Olivetto J., Chahla J., Serra Cruz R. and LaPrade R.F. (2016).Medial meniscal allograft transplantation: the bone plug technique. Arthrosc Tech, 5: e329–e335.

[40]. Hurley E.T., Davey M.S., Jamal M.S., Manjunath A.K., Kingery M.T., Alaia M.J. and Strauss E.J. (2020). High rate of return-to-play following meniscal allograft transplantation. Knee Surg Sports Traumatol Arthrosc, 28(11): 3561–3568.

[41]. Liravi F. and Toyserkani E. (2018). A hybrid additive manufacturing method for the fabrication of silicone bio-structures: 3D printing optimization and surface characterization. Mater Des, 138: 46–61.

[42]. Jacob G., Shimomura K., Krych A.J., and Nakamura N. (2019). The meniscus tear: a review of stem cell therapies. Cells, 9 (1): 92.

[43]. Dhandayuthapani B., Yoshida Y., Melawi T. and Kumar D.S. (2011). Polymeric scaffolds in tissue engineering application: a review. Int J Polym Sci, 1–19.

[44]. Myers K.R., Sgaglione N.A. and Goodwillie A.D. (2014). Meniscal scaffolds. J Knee Surg, 27:435–442.

[45]. Stärke C., Kopf S. and Becker R. (2017). Indikation und Grenzen des Meniskusersatzes. Orthopade, 46:831–838.

[46]. Makris E.A., Hadidi P. and Athanasiou K.A. (2011). The knee meniscus: structure-function, pathophysiology, current repair techniques, and prospects for regeneration. Biomaterials, 32 (30): 7411–7431.

[47]. Gloria A., De Sands R. and Ambrosin L. (2010). Polymer-based composite scaffolds for tissue engineering. J Appl Biometer Biomecb, 81:57-67.

[48]. Ko H.F., Sfeif C. and Kumra P.N. (2010). Novel synthesis strategies for natural polymer and composite biomarerials as potential scaffolds for tissue engineering. PhilosTrans A Matb Pbys Eng Sci, 368:1981-1997.

[49]. Rongen J.J., van Tienen T.G., van Bochove B., Grijpma D.W. and Buma P. (2014). Biomaterials in search of a meniscus substitute. Biomaterials, 35:3527–3540

[50]. Bulgheroni P., Murena L., Ratti C., Bulgheroni E., Ronga M. and Cherubino P. (2010). Follow-up of collagen meniscus implant patients: clinical, radiological, and magnetic resonance imaging results at 5 years. Knee, 17:224–229.

[51]. Hoffman A.S. (2002). Hydrogelsfor biomedical applications. Adv Drug DelivRev, 54:3-12.

[52]. Sarem M., Mozrarzadeh F., Mozaferi M. and hasrri V.P. (2013). Optimization strategies on the structural modeling of gelatin/chlrosan scaffolds to mimic human meniscus tissue. Mater Set Eng Mater Biol Appl, 33:4777-4785.

[53]. Tan H. and Marra K.G. (2010). Injectable, biodegradable hydrogels for tissue engineering applications. Materials., 3:1746-1767.

[54]. Narayanan G., Verneker V.N., Kuyinu E.L. and Laurencin C.T. (2017). Poly (lactic acid)-based biornarerials for orthopaedic regenerative engineering. Adv Drug DelivRev, 15:247–276.

[55]. Verdonk P., Beaufils P., Bellemans J., Djian P., Heinrichs E.L., Huysse W., Laprell H., Siebold R., Verdonk R. and Actifit Study Group (2012). Successful treatment of painful irreparable partial meniscal defects with a polyurethane scaffold: two-year safety and clinical outcomes. Am J Sports Med, 40 (4):844 –853.

[56]. Baynat C., Andro C., Vincent J.P., Schiele P., Buisson P., Dubrana F. and Gunepin F.X. (2014). Actifit®synthetic meniscal substitute: Experience with 18 patients in Brest, France. Orthop Traumatol Surg Res, 100:S385–S389.

[57]. Bouyarmane H., Beaufils P., Pujol N., Bellemans J., Roberts S., Spalding T., Zaffagnini S., Marcacci M., Verdonk P., Womack M. and Verdonk R. (2014). Polyurethane scaffold in lateral meniscus segmental defects: Clinical outcomes at 24 months follow-up. Orthop Traumatol Surg Res, 100 (1):153–157.

[58]. Dhollander A., Verdonk P. and Verdonk R. (2016). Treatment of painful, irreparable partial meniscal defects with a polyurethane scaffold. Midterm clinical outcomes and survivor analysis. Am J Sports Med, 44:2615-2621.

[59]. Filardo G., Kon E., Perdisa F., Sessa A., Di Martino A., Busacca M, Zaffagnini S. and Marcacci M. (2017). Polyurethane-based cell-free scaffold for the treatment of painful partial meniscus loss. Knee Surg Sports Traumatol Arthrosc, 25 (2):459–467.

[60]. Leroy A., Beaufils P., Faivre B., Steltzlen C., Boisrenoult P. and Pujol N. (2017). Actifit (®) polyurethane meniscal scaffold: MRI and functional outcomes after a minimum follow-up of 5 years. Orthop Traumatol Surg Res, 103:609–614.

[61]. Scotti C., Hirschmann M.T., Antinolfi P., Martin I. and Peretti G.M. (2013). Meniscus repair and regeneration: review on current methods and research potential. Eur Cell Mater, 26:150-170.

[62]. Mandal B.B., Park S.H., Gil E.S. and Kaplan D.L. (2011). Multilayered silk scaffolds for meniscus tissue engineering. Biomaterials, 32(2): 639–651.

[63]. Ramakrishna S. (2009).Textile-based scaffolds for tissue engineering. Advanced Textiles for Wound Care, 289–321.

[64]. El-Amin S., Kelly N., Pallotta N., Hammoud S., Lipman J., Ma Y., Holloway J., Lowman A., Palmese G., Warren R. and Maher, SA. (2011). Design and evaluation of a synthetic fiber-reinforced hydrogel meniscal replacement. ORS Annual Meet, 417.

[65]. Holloway J.L., Lowman A.M., VanLandingham M.R. and Palmese G.R. (2014). Interfacial optimization of fiber-reinforced hydrogel composites for soft fibrous tissue applications. Acta Biomater, 10(8): 3581–3589.

[66]. Bilgen B., Jayasuriya C.T. and Owens B.D. (2018). Current concepts in meniscus tissue engineering and repair. Adv Healthc Mater, 7: e1701407.

[67]. Lyons L.P., Hidalgo Perea S., Weinberg J.B., Wittstein J.R. and McNulty A.L. (2019). Meniscus-Derived matrix bioscaffolds: effects of concentration and cross-linking on meniscus cellular responses and tissue repair. Int J Mol Sci, 21(1):44.

[68]. Shemesh M., Shefy-Peleg A., Levy A., Shabshin N., Condello V., Arbel R. and Gefen A. (2020). Effects of a novel medial meniscus implant on the knee compartments: imaging and biomechanical aspects. Biomech Model Mechanobiol, 19(6): 2049 – 2059.

[69]. Moran C.J., Busilacchi A., Lee C.A., Athanasiou K.A. and Verdonk P.C. (2015). Biological augmentation and tissue engineering approaches in meniscus surgery. Arthroscopy, 31: 944–955.

[70]. Tucker B., Khan W., Al-Rashid M. and Al-Khateeb H. (2012). Tissue engineering for the meniscus: a review of the literature. Open Orthop J, 6: 348–351.

[71]. Kremer A, Ribitsch I, Reboredo J, Dürr J, Egerbacher M., Jenner F. and Walles H. (2017). 3D co-culture of meniscal cells and mesenchymal stem cells in collagen type I hydrogel on a small intestinal matrix a pilot study towards equine meniscus tissue engineering. Tissue Eng Part A 23 (9): 390–402.

[72]. Vadodaria K., Kulkarni A., Santhini E. and Vasudevan P. (2019). Materials and structures used in meniscus repair and regeneration: a review. BioMedicine 9:2.

[73]. Chen C., Song J., Qiu J. and Zhao J. (2020). Repair of a meniscal defect in a rabbit model through use of a Thermosensitive, injectable, in situ Crosslinked hydrogel with encapsulated bone Mesenchymal stromal cells and transforming growth factor β1. Am J Sports Med, 48:884–894.

[74]. Rothrauff B.B., Sasaki H., Kihara S., Overholt K.J., Gottardi R., Lin H., Fu F.H., Tuan R.S. and Alexander P.G. (2019). Point-of-care procedure for enhancement of meniscal healing in a goat model utilizing Infrapatellar fat pad-derived stromal vascular fraction cells seeded in Photocrosslinkable hydrogel. Am J Sports Med, 47 (14):3396–3405.

[75]. DePhillipo N.N., LaPrade R.F., Zafagnini S., Mouton C., Seil R. and Beaufls P. (2021). The future of meniscus science: international expert consensus. J Experiment Orthopaedi, 8:24.

[76]. Chen M., Feng Z., Guo W., Yang D., Gao S., Li Y., Shen S., Yuan Z., Huang B., Zhang Y., Wang M., Li ., Hao L., Peng J., Liu S., Zhou Y. and Guo Q. (2019). PCL-MECM-based hydrogel hybrid scaffolds and meniscal Fibrochondrocytes promote whole meniscus regeneration in a rabbit Meniscectomy model. ACS Appl Mater Interfaces, 11:41626–41639.

[77]. Vrancken A.C., Eggermont F., van Tienen T.G., Hannink G., Buma P., Janssen D. and Verdonschot N. 2016). Functional biomechanical performance of a novel anatomically shaped polycarbonate urethane total meniscus replacement. Knee Surg Sports Traumatol Arthrosc, 24 (5):1485–1494.

[78]. Vrancken ACT, Hannink G, Madej W, Verdonschot N., van Tienen T.G. and Buma, P. (2017). *In vivo* performance of a novel, anatomically shaped, total meniscal prosthesis made of polycarbonate urethane: a 12-month evaluation in goats. Am J Sports Med, 45:2824–2834.

1/22/2022