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A New Approach to Arthroscopic Stitching of the Knee Joint Meniscus: A Mathematical Justification

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Abstract

Background: This article presents a mathematical justification for a new approach to arthroscopic stitching of the knee joint meniscus, based on a 3D computer model of the meniscus developed using the COMPASS-3D (APMFEM) program and AutodeskInventorPRO. The research with the patent RK No. 35413 dated 10.12.2021, titled "Method of arthroscopic stitching of the meniscus of the knee joint" builds upon the work of Yu.V. Labunsky.

Methods: Mathematical analysis was performed to compare two methods of stitching the meniscus: the new oblique-vertical stitch and the classical vertical stitch. The contact area of the meniscus tissues in the area of the rupture was measured for both stitching methods.

Results: The findings demonstrate that the new oblique-vertical stitch offers a 1.5 times larger contact area of the meniscus tissues in the area of the rupture, compared to the classical vertical stitch. Additionally, the new method provides a more significant grip on the radial and circular fibers of the meniscus, surpassing the capabilities of the classic seam.

Conclusion: The results of this study can be utilized to develop practical recommendations for traumatologists regarding arthroscopic stitching of the meniscus in the knee joint. The new approach, supported by mathematical analysis and a 3D computer model, offers improved outcomes in terms of contact area and grip on the meniscus fibers, potentially leading to enhanced surgical techniques and patient outcomes.

Keywords: Biomechanics, Mathematical Justification, Finite Element Method, Knee Joint, Menisci, Meniscus Stitch

Conflicts of Interest: *None declared*
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Introduction

KJ meniscus injuries are one of the most common injuries in sports medicine (1, 2). Currently, there is no single tactic to treat fresh meniscus ruptures. There are no clear recommendations for using the meniscus suturing technique depending on the type of injury (3). Meniscectomy significantly increases the risk of developing osteoarthritis (OA) of the knee joint after 20 years (4).

The preservation of menisci during surgery can slow down the progression of osteoarthritis in the knee joint and lead to good functional results in the long-term period of surgery (5, 6). In this regard, the preservation of menisci during arthroscopic operations is an urgent problem of modern traumatology in preventing the development and progression of osteoarthritis of the knee joint, reducing unsatisfactory results in long-term surgical treatment. Therefore, it is desirable to develop a method of meniscal stitch, which can increase the healing of the meniscus and reduce complications avoiding meniscectomy (7).

↑What is "already known" in this topic:
Preservation of the meniscus following knee trauma using arthroscopic stitching is highly desirable, albeit challenging.

→What this article adds:
The new oblique-vertical stitch offers a greater contact area and a tighter grip on the radial and circular fibers of the meniscus compared to classical vertical-only methods; thus it may potentially improve patient outcomes.

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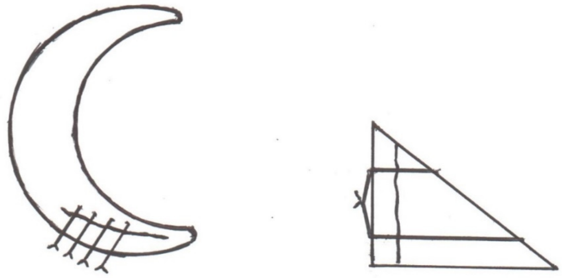
We introduce a novel arthroscopic repair technique in treating meniscus ruptures that applies to most parts of the meniscus, except for the posterior horn of the lateral meniscus. This method can stitch the meniscus tissue without capsule and subcutaneous tissue and preserve the meniscus's normal biomechanics during movement.

The finite element method (FEM) is widely used in mathematical modeling in medicine, which allows us to study structures with complex geometry and take into account the features of a real object to the fullest account. Three-dimensional modeling provides an accurate picture of the distribution of stresses and their concentration zones. The purpose of the study is to perform mathematical (biomechanical) substantiation of arthroscopic stitching of the knee joint meniscus using the vertical-oblique technique in contrast to the classical vertical technique.

Methods

To stitch the meniscus of the KJ, the authors have developed a new oblique-vertical stitch of the meniscus, for which the patent of the Republic of Kazakhstan for invention No. 35413 dated 10.12.2021 ("Arthroscopic stitching method of the knee joint meniscus") was obtained (8).

The scheme of the formed new oblique-vertical stitch of the KJ meniscus is shown in Figure 1.



a) b)

a - top view; b – side view

Figure 1. Diagram of the formed oblique-vertical stitch of the KJ meniscus

Currently, the finite element method (FEM) is widely used in medical applications for mathematical modeling. This method allows for the study of structures with complex geometry and the most comprehensive consideration of the characteristics of real objects (9). The COMPASS-3D(APMFEM) and AutodeskInventorPRO programs were used for the computer implementation of the FEM (10). To mathematically justify the arthroscopic stitching of the knee joint meniscus using a new method, we created a 3D computer model of the meniscus based on the research by Yu V. Labunsky on average sizes (Table 1) (11). The 3D computer model of the knee joint meniscus is presented in Figure 2.

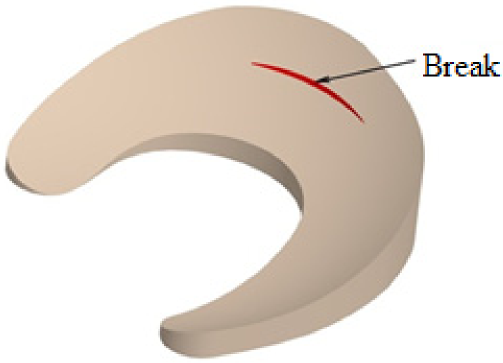


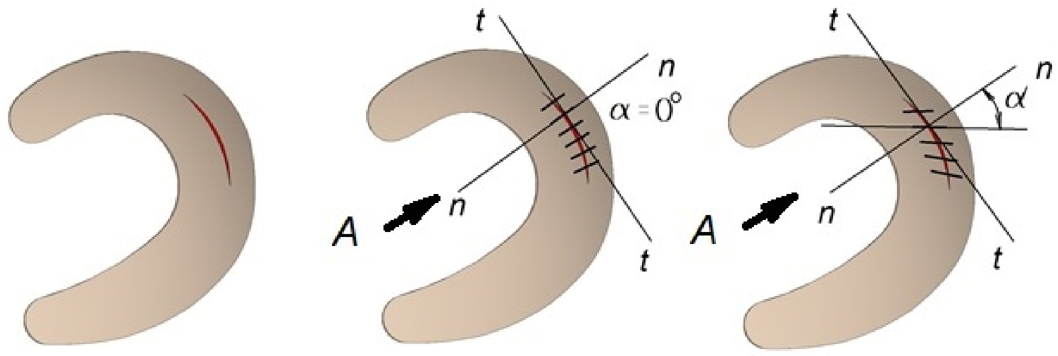
Figure 2. 3D computer model of KJ meniscus

The technique

The essence of the new method of arthroscopic stitching of the knee joint meniscus is that the spinal needle is carried out from the inside to the outside of the KJ, through the thickness of the meniscus – at the lower edge, through the capsules and is removed through a small incision of the skin. The suture material is injected through the spinal needle. Then the end of the suture material is seized with a clamp and removed from the joint cavity. Holding the suture material with a clamp, the spinal needle is removed from the meniscus and pulled back into the knee joint cavity. Then, the spinal needle with suture material is moved out 3 mm above and 3 mm away from the initial puncture through the thickness of the meniscus – at the upper edge. In doing so, the suture material is positioned obliquely vertically at an angle of 45 to the axial line of the meniscus to form an oblique-vertical stitch (Figure 3). The needle is removed through a small incision of the skin. The suture material is extracted from the knee joint cavity with a clamp, and the ends of the threads are tied in the

Table 1. Dimensions of the articular menisci of the KJ of an adult (according to Yu.V. Labunsky, 1968) (11)

Indicator	Medial menisci sizes			Lateral menisci sizes		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Width (mm)						
Anterior horn	6,0	13	8,3	8,0	1 7	11,0
Body	5,0	16	9, 0	8,0	20	11,7
Posterior horn	7,0	22	16,0	7,0	15	9,8
Thickness (mm)					10,6	6,8
Anterior horn	4 , 5	9 , 4	6,7	4,0		
Body	8,0	11.5	6, 5	4,2	10,8	6, 8
Posterior horn	3,7	10,2	7,0	4,5	10,0	6,8
Distance between horn ends (sm)	1,5	3,3	2,6	0,6	1,7	1,1
Length of the outer circumference (sm)	7,0	10,2	8,7	6,2	10,2	8,5



a) b) c)
a - damaged meniscus, b – vertical stitch (classical), c - new oblique-vertical stitch (authors)

Figure 3. Types of arthroscopic sutures for KJ meniscus injuries

extracapsular space under arthroscopic visualization of the meniscus rupture zone until its edges are closed entirely.

Results

We consider a section of the meniscus of the KJ, consisting of two sutures section t-t, the ruptured part of the meniscus, and the stitch projection obtained with the classical method of stitching the meniscus and with the new stitching method (Figure 4).

Below, a calculation scheme is used and the coverage area of the damaged meniscus site of the KJ with the classical method of stitching and the new method of stitching is mathematically described (Figure 5).

According to Figure 4a, the coverage area with the classical stitching method is determined by the formula of the rectangle ABCD site (12):

$$S_{vs} = a \cdot b, \quad (1)$$

where a is the distance between two stitches, and b is the stitch height.

The area covered by the new oblique-vertical stitch will be determined by the formula of the site of the parallelogram KLMN (12) (Figure 4b):

$$S_{os} = a \cdot (b + d) = a \cdot c \cdot sin\alpha, \quad (2)$$

Where a is the distance between two stitches, b+d is the stitch height, c is the stitch length, and α is the angle of stitch inclination.

To compare the stitches, we substitute numerical values: a = 6 mm, b = 6 mm,

d = 3 mm. According to calculations, we get

$S_{vs} = a \cdot b = 6 \cdot 6 = 36mm^2$,

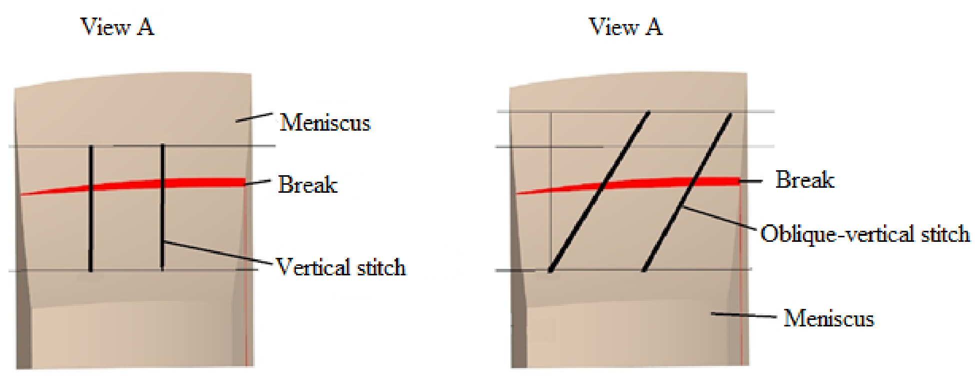
$S_{os} = a \cdot (b + d) = 6 \cdot (6 + 3) = 54mm^2$.

The obtained values showed us that the contact area at the point of rupture created by the oblique-vertical stitch is 1.5 times higher than with a vertical stitch, and this explains the effectiveness of the new oblique-vertical stitch compared to the classic vertical stitch.

Analysis of the meniscus structure (Figure 6) also confirms the effectiveness of the new oblique-vertical stitch since it best captures radial and circular fibers and is located at an angle to them. The classic vertical stitch runs parallel to the radial fibers, and their full-fledged capture is practically difficult (Figure 7).

Discussion

We implemented a 3D computer model of the meniscus according to the research of Yu.V. Labunsky and mathematical modeling by the finite element method (FEM) us-



a) b)
a - vertical stitch (classical), b - new oblique-vertical stitch

Figure 4. A section of the KJ meniscus consisting of two stitches

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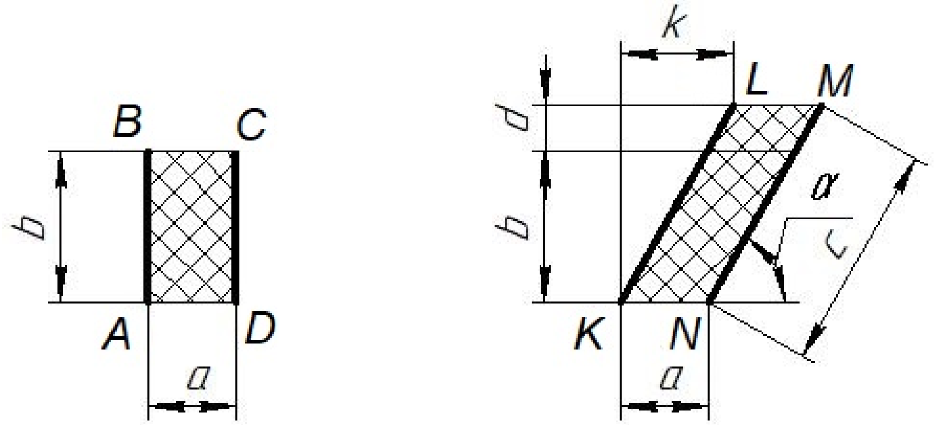
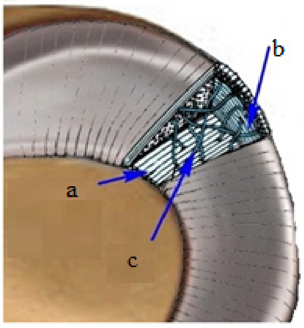


a) b)
a – vertical stitch (classical), b – new oblique vertical stitch

Figure 5. The damaged meniscus site's design scheme and mathematic coverage area with two stitches



a - radial fibers; b - longitudinal (circular) fibers; c - penetrating (perforated) fibers

Figure 6. Meniscus structure, lateral, top view (13)

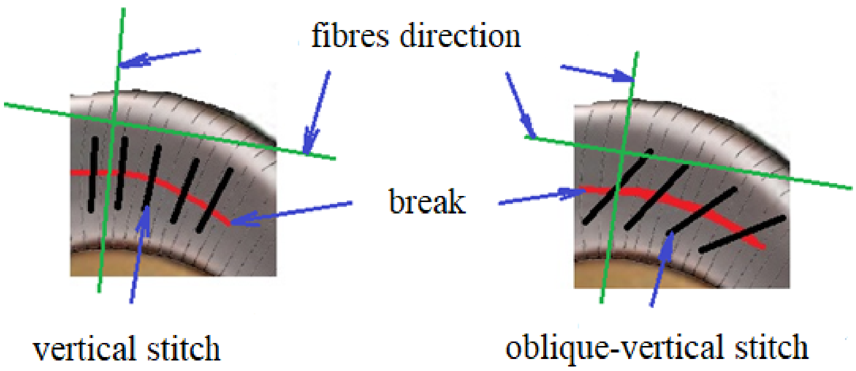


Figure 7. Stitches layout concerning the fibers of the meniscus

ing the COMPASS-3D program (APMFEM), AutodeskInventorPRO to compare the physical properties of the new technique with the classical technique. The results showed that the developed oblique-vertical stitch was superior in comparison with the classical seam. As a result of calculations, it is shown that the contact area of the meniscus tissues in the area of the rupture created by the developed oblique-vertical suture was 1.5 times higher than with the classical vertical stitch. The newly developed method of arthroscopic stitching (patent RK No. 35413 of 10.12.2021 "Method of arthroscopic stitching of the knee joint meniscus") for the knee joint meniscus offers a significant grip on the radial and circular fibers of the meniscus. Unlike the classic vertical seam, which runs parallel to the radial fibers and provides minimal capture, the new method is positioned at an angle to the fibers, allowing for a more substantial grip on them.

Conclusion

The new oblique-vertical suture technique introduced herein provided a superior grip on the radial and circular fibers of the meniscus and a higher contact area compared to the classical vertical suture. These features may deem the oblique-vertical technique a better option for repairing meniscal ruptures. Thus, we recommend researchers conduct clinical trials to assess the clinical utility of this technique by evaluating its effects on clinical outcomes.

Authors' contribution

All authors have contributed equally to developing the concept, implementation, processing of results, and writing the article. We declare that this material has not been published before and is not under consideration by other publishers.

Conflict of Interests

The authors declare that they have no competing interests.

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