Technical Note

Absorbable Nail Fixation of Biologic Membrane for Treatment of Cartilage Defects by Matrix-Induced Autologous Chondrocyte Implantation

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Abstract: Injuries to articular cartilage caused by a variety of factors are common clinically and can impair quality of life and lead to long-term dysfunction in a manner similar to osteoarthritis, which has led to the development of various repair techniques for articular cartilage injury. Although each technique has its own limitations and advantages, matrix-induced autologous chondrocyte implantation has been widely used and achieved good clinical results. We present a technique for fixing biofilms with absorbable nails with a "Roman column structure" as the main structure. The described technique allows stable immobilization of the biofilm while ensuring that subsequent cartilage damage repair can proceed smoothly.

Articular cartilage is hyaline cartilage composed of chondrocytes and extracellular matrix.[1,2] It can reduce friction between bones, absorb vibration between joints, and play an important role in maintaining joint function. Cartilage injury is common in clinical practice, and factors such as sports injury, bone disease, and age can all cause damage to human articular cartilage tissue, affecting its structure and function.[3] Joint cartilage injury may impair quality of life in a manner similar to severe osteoarthritis and lead to long-term dysfunction.[4,5,6] Because of the lack of vascular tissue in human articular cartilage and the dense extracellular matrix of articular cartilage, it cannot provide blood supply, and its nutrition comes from the nourishment of surrounding joint synovial fluid. Once damaged, it is difficult to regenerate and repair.[7]

There are many methods for treating articular cartilage injury in clinical practice, including joint cleaning, inlay-forming techniques, microfracture techniques,[8] and bone cartilage transplantation technology.[9,10] Among them, joint cleaning and microfracture techniques are simple and can alleviate symptoms but cannot form hyaline cartilage at the injured site, and therefore the long-term effect is poor. Bone cartilage transplantation includes both autologous cartilage transplantation and allogeneic cartilage transplantation; however, autologous cartilage transplantation can damage the donor site, whereas allogeneic cartilage transplantation has limited sources. Therefore, the aforementioned cartilage-repair methods all have their own shortcomings.

In recent years, with the development of tissue-engineering technology, matrix-induced autologous chondrocyte implantation, also known as matrix-induced autologous chondrocyte implantation (MACI), has gradually become common in clinical practice.[11] MACI refers to the use of biomaterials to cover the cartilage damage area after microfracture surgery and mainly is suitable for patients with full-thickness cartilage lesions and minimal or no involvement of subchondral bone, and whose symptoms persist after sufficient nonsurgical treatment.[12,13] In addition, its clinical benefits have been recognized in many clinical trials: Griffin et al.[14] demonstrated in the horse model that MACI-repaired cartilage can match certain characteristics of natural cartilage and has considerable repair effects. Dai et al.[15] demonstrated in a 5-year follow-up experiment that MACI surgery is a promising and effective cell therapy method that can provide both subjective and objective improvements for patients. In addition, Husen et al.[16] mentioned in a

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Received November 21, 2023; accepted February 8, 2024.

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2212-6287/231693
https://doi.org/10.1016/j.eats.2024.102984

review published in 2022 that MACI may be a more sustainable option for football players after knee injury. After the gradual abandonment of periosteal patches due to significant technical challenges and adverse events,[17] MACI products at home and abroad are mainly divided into 2 categories: membrane products and gel products. Membrane products need to be fixed after being implanted into the injured area of the patient in order to play their role. The commonly used fixation methods are fibrin glue[18] and absorbable sutures, which fix the membrane at the damaged area in a manner similar to "glue."[6,15] This Technical Note introduces a method of using absorbable nail (Biofix; Bioscience Ltd., Tampere, Finland) fixation membrane products[19] and shows the technique in Video 1, in order to achieve a more stable fixation effect.

Fig 1. Arthroscopic image viewing from the anterior lateral portal of the patient's left knee with the patient in the supine position. Use a shaver to scrape off the cartilage on the surface of the damaged joint cartilage. Arrow indicates area of interest.

Surgical Technique (With Video Illustration)

Patient Positioning and Preparation

The patient is placed in a supine position with their knees above the edge of the operating table, and their lower limbs are prepared and covered in a standard manner. Bleed the limbs and inflate the tourniquet to 300 mm Hg. Before surgery, it is necessary to confirm a sufficient supply of MACI grafts and sufficient preparation of surgical instruments such as shavers, arthroscopy, and probing hooks.[6]

Cleaning of Damaged Cartilage and Determination of Defect Area

The surgery adopts 2 approaches, through which arthroscopy and shaver enter the site of damaged cartilage. First, use a shaver to scrape off the cartilage on the surface of the damaged joint cartilage (Fig 1, Video 1). Second, use a scraper to scrape off the unstable cartilage until it reaches the normal cartilage area (Fig 2, Video 1). Generally, it is advisable to clean it into a stable sloping edge surface of 30° to 45°. Pay attention to clearing the calcified cartilage layer at the base of the defect site but avoid invading the subchondral bone cortex.[20] Then, use a shaver to remove the scraped debris and use a suction device connected to it to suck out the debris (Fig 3, Video 1). After all cleaning is completed, in order to determine the size of the defect area, we use a ruler to measure under arthroscopy (Fig 4, Video 1). In order to obtain the area of the defect more accurately, we can also use the Tracemo software invented by Professor Ao Yingfang and his team from the Third Hospital of Beijing Medical University, using the relationship between rulers, pixels, and scales to obtain the area of the defect area.[21]

Graft Preparation and Implantation

After cleaning of the damaged area and the measurement of the size of the damaged area are completed, treatment of the graft begins. Place the preprepared sterile porcine peritoneum (Shaanxi Baiao Biological Regenerative Medicine Co., Ltd., Shaanxi, China) on a sterile foil, with the smooth and shiny side of the membrane facing downwards. Subsequently, based on the measured defect area data, sterile scissors are used to cut a porcine peritoneal graft that meets the size and shape requirements of the defect area.[6] Afterwards, rehydrate the trimmed porcine peritoneum for 5 to 10 minutes.

After preparing the graft, use a microfracture instrument to perform microfracture treatment on the defect site—several small holes with a depth of 3 mm and a diameter of 2 mm are drilled at a spacing of 3 mm at the defect site (Fig 5, Video 1), allowing some bone marrow and blood to seep out of the holes. Place the treated

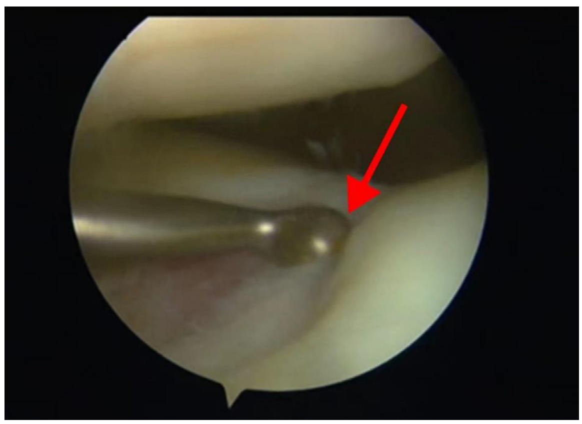

Fig 2. Arthroscopic image viewing from the anterior lateral portal of the patient's left knee with the patient in the supine position. Use a scraper to scrape off the unstable cartilage until it reaches the normal cartilage area. Arrow indicates area of interest.

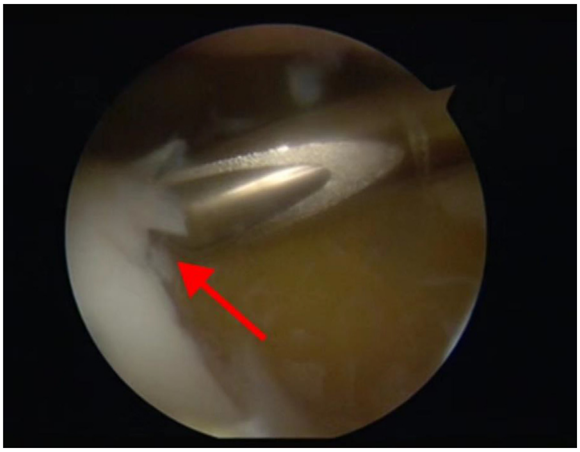

Fig 3. Arthroscopic image viewing from the anterior lateral portal of the patient's left knee with the patient in the supine position. Use a shaver to remove the scrap-ed debris and use a suction device connected to it to suck out the debris. Arrow indicates area of interest.

porcine peritoneum on the defect site and unfold it, carefully remove bubbles, and use a 1.5-mm diameter Kirschner wire as a temporary tool to fix the porcine peritoneum to prevent it from slipping (Fig 6, Video 1). Afterwards, a locator is used to locate the defect area, and a drill bit with a diameter of 1.5mm and a scale is used to drill a bone canal with a diameter of 1.5 mm (Fig 7, Video 1). Generally, the depth of the bone canal is determined based on the location of the injury and the gender of the patient—if the injury is patellar cartilage, the depth of the bone canal is chosen to be 15 mm regardless of whether the patient is male or female. If the injury locations are trochlear cartilage and condylar cartilage, for male patients, the depth of the bone canal is chosen as 20 mm or 25 mm, whereas for

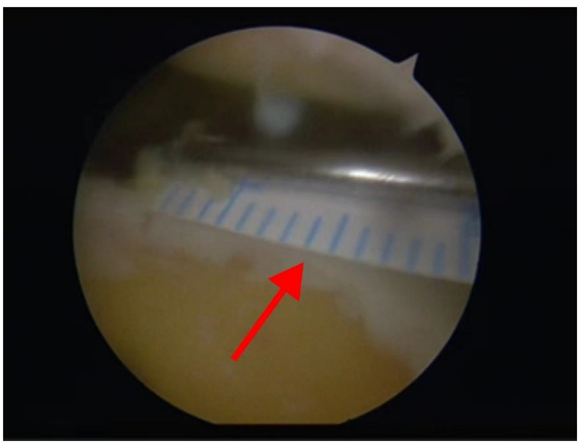

Fig 4. Arthroscopic image viewing from the anterior lateral portal of the patient's left knee with the patient in the supine position. Measure the area of the defect area under arthroscopy with a ruler to prepare for subsequent implantation of the porcine peritoneum. Arrow indicates area of interest.

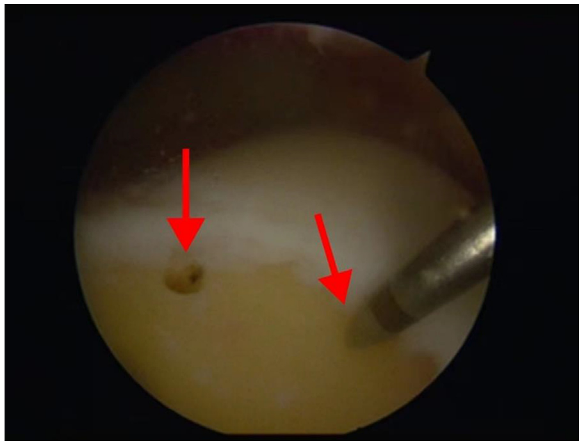

Fig 5. Arthroscopic image viewing from the anterior lateral portal of the patient's left knee with the patient in the supine position. Microfracture is performed with a depth of 3 mm and a diameter of 2 mm using a microfracture instrument at a spacing of 3 mm in the area, allowing some bone marrow and blood to seep out of the holes. Arrows indicate areas of interest.

female patients, the depth of the bone canal is chosen as 20 mm. Finally, use a nail implant to knock the Biofix absorbable nail with the "Roman column" structure into the bone canal (Fig 8, Video 1), and stem cells in the bone marrow can flow out to the injured site along the nail to complete subsequent damage repair. After the fixation of the porcine peritoneum is completed, remove the Kirschner wire and clean the excess membrane with a shaver to make the joint surface smooth.

Joint Reduction and Closure of Surgical Incisions

After the initial fixation is completed, passively move the joints 5 to 10 times and observe whether the porcine peritoneum has fallen off.[6] If the porcine

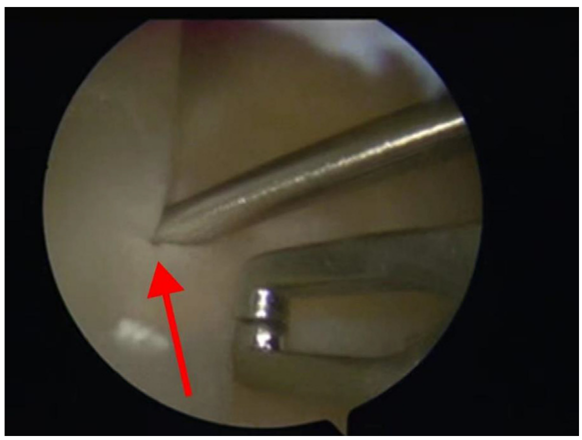

Fig 6. Arthroscopic image viewing from the anterior lateral portal of the patient's left knee with the patient in the supine position. Implanted into the porcine peritoneum and fixed with Kirschner- wires. Arrow indicates area of interest.

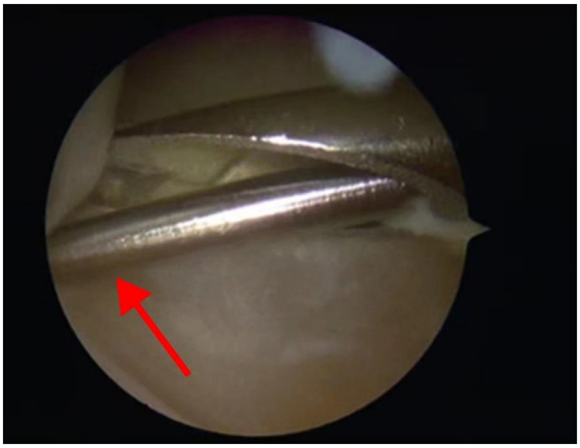

Fig 7. Arthroscopic image viewing from the anterior lateral portal of the patient's left knee with the patient in the supine position. A locator independently developed by Peking University Third Hospital was implanted. A 20-mm deep nail path was drilled using a 1.5-mm diameter drill bit. Arrow indicates area of interest.

peritoneum falls off, it should be refixed. If it does not fall off, the surgical site should be closed—the wound is closed in layers using 3-0 MONOCRYL for the subcutaneous tissue and running 3-0 MONOCRYL for the skin. A hinged knee brace is fitted and locked in full extension.[6]

Postoperative Rehabilitation

Postoperative rehabilitation is divided into 3 stages. Week 0-6 is early rehabilitation training. In addition to joint mobility exercises, patients need to wear a straight splint for 2 weeks to fix their knees to the 0° position for both muscle-strengthening exercises and weight-bearing exercises. Joint range of motion exercises include full dorsiflexion and full plantar flexion

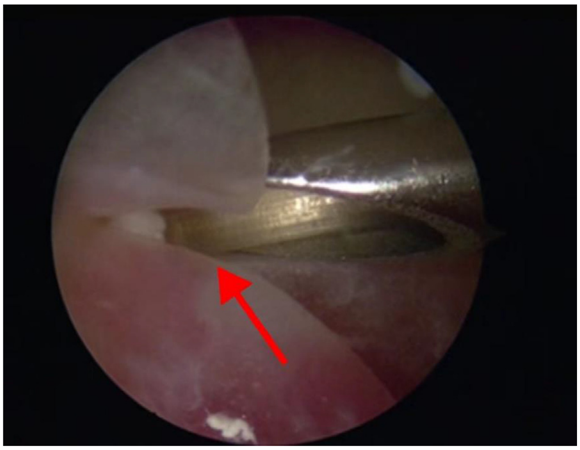

Fig 8. Arthroscopic image viewing from the anterior lateral portal of the patient's left knee with the patient in the supine position. An absorbable nail with a Roman column structure was inserted. Arrow indicates area of interest.

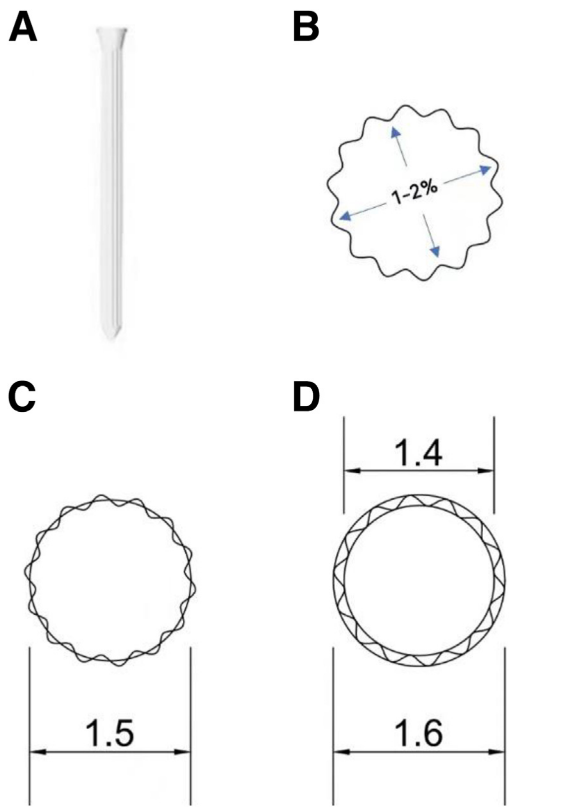

Fig 9. Biofix absorbable nail. (A) Overview of nails with a "Roman Column" structure. (B) After entering the human body, nails can expand by 1% to 2%, which can increase the initial fixation strength. The actual maximum outer diameter of nails is 1.6 mm (D), the minimum outer diameter is 1.4 mm (D), and the average is 1.5 mm (C). The height of the groove on the surface of the nail is 0.2 mm, and the "Roman column" structure enhances the initial fixation strength, increasing the nail's resistance to pull-out and rotation. By providing a feasible method for reproducible, stable, and accurate MACI graft fixation using Biofix absorbable nails, we believe that the described technology can provide valuable supplements to the surgeon's toolbox for repairing focal cartilage defects. (MACI, matrix-induced autologous chondrocyte implantation.)

exercises of the ankle joint, contraction and relaxation exercises of the quadriceps femoris muscle, and continuous passive knee flexion exercises within the painless range (4-6 weeks after surgery). Muscle-strengthening exercises involve stretching and relaxing the front and rear thigh muscles in a fully extended knee position. Weight-bearing practice involves not carrying weight or partially carrying weight on the toes with the support of a cane (if there is cartilage damage in the non—weight-bearing area, a straight splint can be used as appropriate to fully carry the weight).

Week 6-12 is midterm training. At weeks 6 to 8, if the patient can fully straighten and bend their knees by more than 100°, without pain or swelling while walking, and gradually remove assistive devices such as

Table 1. Advantages and Disadvantages, Including Risks and Limitations, of the Entire Technique

Advantages	Disadvantages, Risks, and Limitations
Less trauma to the joint	High demands on surgeons
Fast recovery from trauma	The learning cycle of the technique is long
Aesthetic appearance after repairing the damage	Inexperience may lead to collagen membrane tears
The nails with a Roman column structure are stable, with the ability to resist twisting and pulling out.	
The nails are absorbable and will not leave marks after the damage is repaired	

crutches, they can use a weight reducer or hydrotherapy to gradually transition to full weight-bearing

After the 12 weeks, it is the recovery period for later activities. If the patient can tolerate jogging without pain or swelling, they can gradually walk quickly within their tolerance range. Jogging should be reviewed 6 months after surgery before deciding whether to start.

Discussion

The traditional repair process of knee joint cartilage injury often adopts an open joint incision approach, which may cause significant trauma to the surgical site and slow down the recovery speed of the injured joint. At the same time, this method will generate large scars at the repair site, which will reduce the aesthetics of the joint.[22] On the contrary, the technique of open joint incision was not used in the surgical procedure we described, and all operations are performed under arthroscopy, which has the advantages of minimal joint trauma, fast recovery from injury, and better attention to cosmetic appearance.[23]

In addition to the advantages of using arthroscopy, the Biofix absorbable nail (Fig 9) used in this technology also has its other advantages—the nail has a "Roman column" structure, with small grooves on the column, and stem cells in the bone marrow can flow out smoothly along the grooves, which is conducive to the repair of soft bone injuries. Furthermore, the structure of the "Roman column" also endows the nail with strong resistance to torsion and pull-out, making it more stable. Meanwhile, the nail is an absorbable nail that can gradually be absorbed without leaving any marks during the patient's recovery process. From an operation perspective, the overall process of driving nails is more convenient, and compared with methods such as using glue to fix collagen membranes, this operation does not significantly increase the overall difficulty of the surgery.

However, the method of using Biofix absorbable nails to fix the collagen membrane also has certain drawbacks—because of the overall surgical process being performed under arthroscopy, which requires high demands from surgeons, the learning curve of this technology is long. In addition, even surgeons who have learned this technique may still experience collagen membrane tears caused by inexperience in operation, which is a clinically noteworthy adverse consequence (Table 1).

Arthroscopic image viewing from the anterior lateral portal of the patient's left knee with the patient in the supine position. Use a shaver to scrape off the cartilage on the surface of the damaged joint cartilage. By providing a feasible method for reproducible, stable, and accurate MACI graft fixation using Biofix absorbable nails, we believe that the described technology can provide valuable supplements to the surgeon's toolbox for repairing focal cartilage defects.[6]

Disclosures

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: This work was supported by Beijing Natural Science Foundation (L222065), Haidian innovation transformation special scientific innovation research and development (HDCXZHKC2021213), Beijing Third Hospital Talent Incubation Fund (Young Backbone) (BYSYFY2021038), Third Hospital of Beijing Medical University clinical key project Talent project Class B (BYSYZD2019024), State General Administration of Sport science and technology innovation project (22KJCX007). Y.A. is chairman of the International Cartilage Regeneration and Joint Preservation Society. Z.L. is a committee member of the International Cartilage Regeneration and Joint Preservation Society. All other authors (F.Y., X.G.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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