

Arthroscopic three dimensional autologous chondrocyte transplantation with navigation-guided cartilage defect size assessment

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Abstract

Introduction The treatment of large full thickness cartilage defects with matrix guided autologous chondrocyte transplantation shows promising results. However, in many cases an arthrotomy is needed to implant the cell seeded scaffolds. Recently techniques have been developed for arthroscopically guided ACT implantation. Correct defect mapping, to assess size and depth of the chondral lesions, and precise scaffold preparation and fixation are crucial for successful chondrocyte transplantation and remain to be not sufficiently optimized.

Method In the present study, the geometries of two cartilage defects in cadaver knees were three times assessed, measured and transferred to biodegradable scaffolds with a navigation system by three different executors. The scaffolds were arthroscopically implanted into the cartilage defects.

Results The cartilage defect assessment was reproducible between all executors for all defect geometries. The implanted scaffolds showed a correct defect filling.

Conclusion The study showed the feasibility of an arthroscopic implantation of scaffolds for autologous chondrocytes transplantation. Navigation was a useful tool to exactly assess the cartilage defect geometry and allowed a precise transfer of navigated cartilage defect geometries for individualized scaffold preparation. Navigation can help to accomplish and optimize arthroscopically guided chondrocyte transplantations.

Keywords Cartilage defect · Navigation · Arthroscopic autologous chondrocytes transplantation

Introduction

In recent years, matrix guided autologous chondrocyte transplantation (MACT) for treatment of large full thickness articular cartilage defects is becoming more popular. Brittberg et al. [4] first introduced the technique of the autologous chondrocyte transplantation (ACT) in 1994. Particularly for the treatment of cartilage defects larger than 3 cm² the ACT revealed superior long-term success [2, 15, 16]. The conventional technique is accompanied with periosteum harvest and fixation over the cartilage defects via large skin incisions. Autologous chondrocytes were injected underneath the periosteal flap. Hypertrophy of the periosteum with high rate of revision arthroscopies [17] and the risk of transplant failure up to 20% are major drawbacks of the conventional autologous chondrocyte transplantation.

The matrix guided autologous chondrocytes transplantation (MACT) was developed to address these problems. In a first arthroscopy, small osteochondral plugs are taken from the nonweight bearing cartilage adjacent to the lateral femoral notch. Then the chondrocytes are isolated, cultured and seeded on biodegradable scaffolds. Approximately 3 weeks after the first arthroscopy, the cell-seeded scaffolds are implanted in cartilage defects with sutures or biodegradable devices like plugs or anchors.

With the new technique of the MACT some disadvantages of the ACT could be eliminated [7], but still a mini-open arthrotomy is necessary to implant the chondrocyte-scaffold-composites. A multicenter study evaluating the clinical outcome after ACT claimed that 26% of the

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postoperative procedure related problems can be contributed to arthrotomy [5].

There are some reports about an arthroscopically performed matrix guided ACT [6, 12, 14].

The precise evaluation of defect geometry and the surgically demanding implantation technique under arthroscopy remain challenging for minimally invasive ACT. Navigation has helped to optimize and improve outcomes for certain surgical procedures such as total knee replacement [3, 18, 20] and anterior cruciate ligament (ACL) reconstruction [10, 11, 19].

A recently developed cartilage defect-managing (CDM) module of the Orthopilot navigation system (Aesculap) allowed an assessment of cartilage defect geometries [1] undergoing cartilage repair. The CDM module seems to be intriguing for optimization of autologous chondrocyte transplantation, by its ability to precisely transfer defined defect geometries to 2D surfaces [1]. The present study was made to test the CDM module for its feasibility to perform exact cartilage defect mapping, individualized scaffold preparation and arthroscopical matrix guided chondrocyte transplantation (MACT) in a clinical setup.

Materials and methods

Navigation system

The study was conducted with the OrthoPilot navigation system (B. Braun-Aesculap, Tuttlingen, Germany). After fixation of the rigid bodies with k-wires, the calibration of the navigation system with the assessment of the landmarks was performed as described for the system.

Cartilage defect assessment

Two cadaver knees (left and right) were evaluated in the study. After the adjustment of the navigation system, a defined full thickness cartilage defect was created at the medial femoral condyle via an anteromedial and an anterolateral arthroscopic approach.

The newly developed CDM module was tested by two experienced surgeons with expertise in ACT and navigation and a technician with knowledge of navigation. The three test administrators navigated the defect geometries arthroscopically. The defects were palpated dot by dot with the tip of a straight pointer (Fig. 1). Two defect geometries (one in each knee) were tested. Each defect was palpated three times by each executor and the data were checked regarding the reproducibility of the defect parameter acquisition.

Cartilage defect shape transfer

After the mapping of the chondral defect, the camera system, consisting of a standard arthroscopic camera system (DAVID 1-chip camera PV280, B. Braun-Aesculap) and a transfer platform, was connected to the navigation screen. The arthroscopic camera, including the transfer platform, was used in a sterile manner to duplicate clinical conditions. The camera transferred the picture on a cell-free collagen scaffold (NOVOCART 3D), which can be used for a matrix-assisted ACT. The scaffolds were fixed on the transfer platform. Equal magnification between the collagen scaffolds and the navigation screen could be obtained by overlapping the four red dots on the navigation system screen with four corresponding dots on the transfer platform by changing the distance of the camera to the

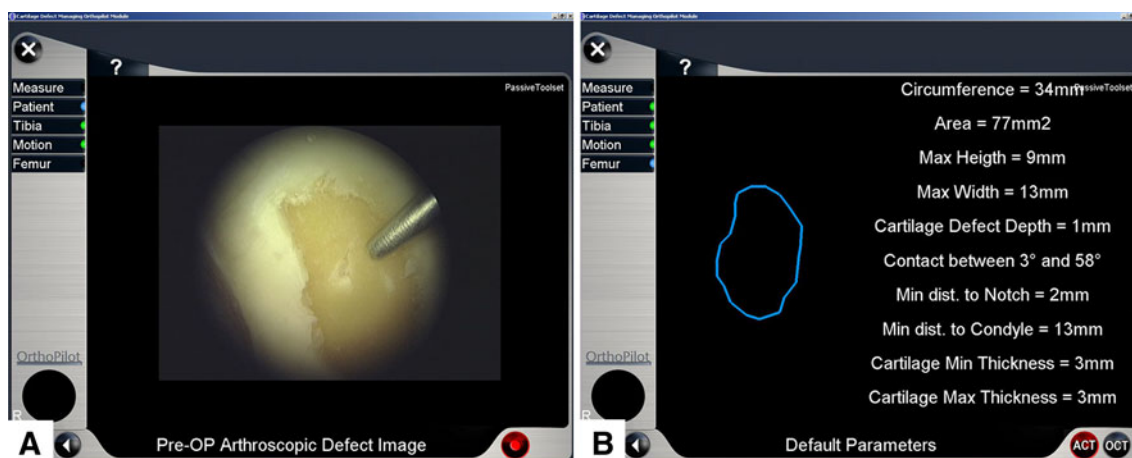


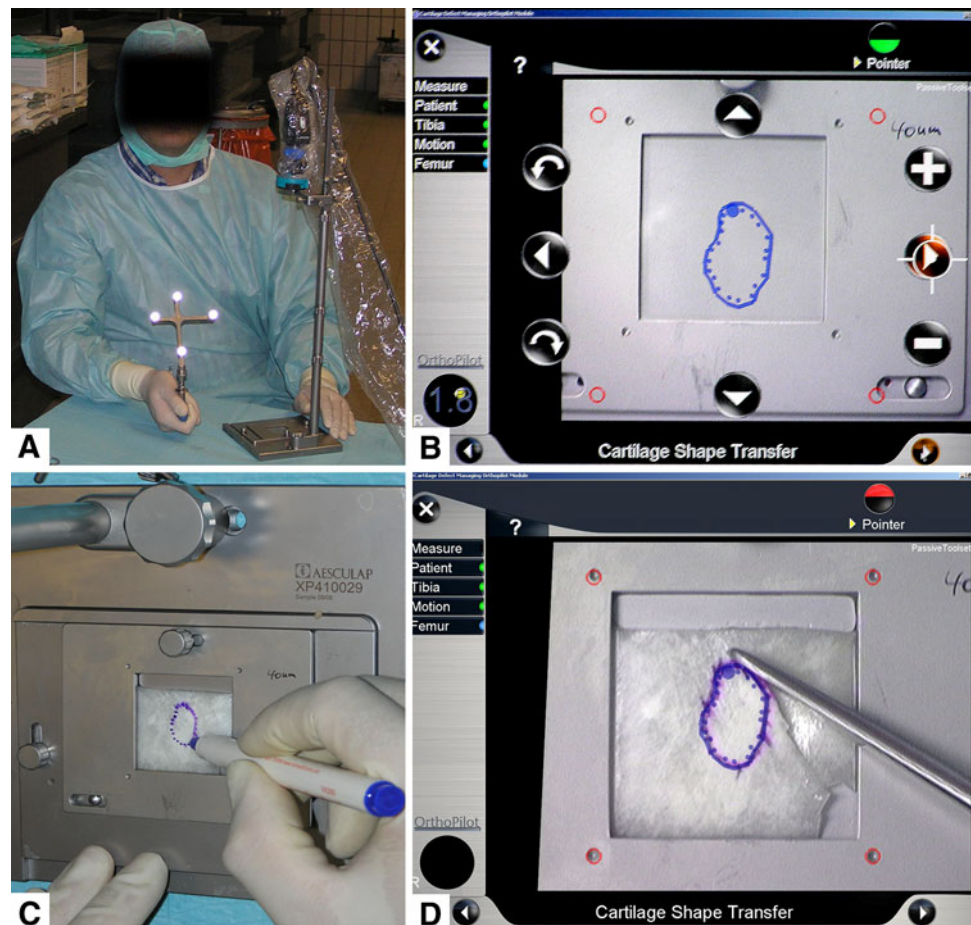
Fig. 1 Cartilage defect assessment. The defect geometry was navigated arthroscopically by pointing the defect area (a). The shape of the defect was immediately analysed by the navigation system (b)

transfer platform and by adjusting the magnification of the camera. The transfer of the defect geometries was marked on the scaffold with a pen, and the navigated dots were followed and adjusted on the navigation screen by three test administrators. The procedure was conducted for all defects ($n = 2$) and repeated three times by all three test administrators. The matrices were then cut to navigation guided defect size with a scissor (Fig. 2).

Arthroscopic implantation of the navigation guided customized scaffold

For the arthroscopic implantation, the navigation guided customized scaffolds were introduced into the joints via an applicator tube. The scaffolds were placed into the cartilage defects with a fleece grasper. The scaffolds were fixed in the defects with bioresorbable pins (PLDLLA Copolymer), which are designed, evaluated and approved for scaffold fixation of MACT in clinical applications (Fig. 3). The degradation time of the pins is 12 months. After fixation of the scaffolds, the heads of the pins were always under the level of the surrounding native cartilage to avoid any adverse side effects to the opposite cartilage.

Fig. 2 Cartilage defect shape transfer. After the mapping of the chondral defect, the OrthoPilot camera system transferred the defect geometry on a collagen scaffold. The matrices were then cut to navigation guided defect size with a scissor (a–d)



Postoperative evaluation

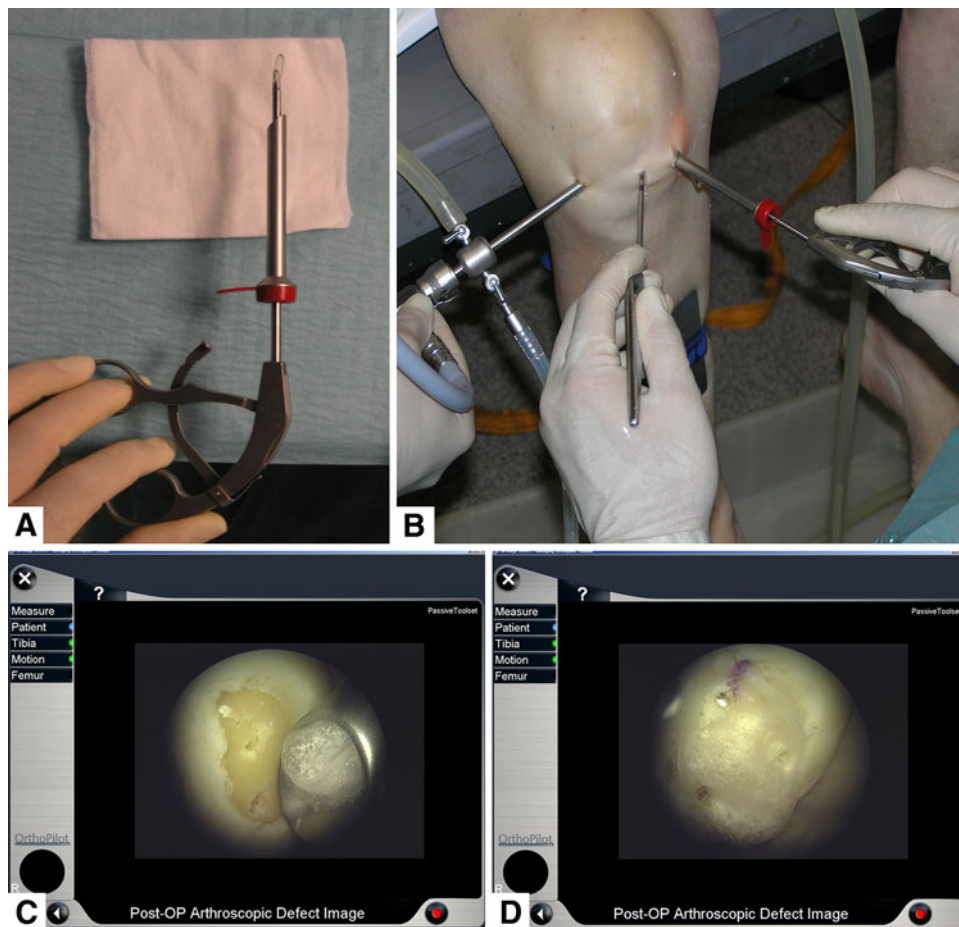
After the arthroscopic procedures, the two cadaver knees were opened via an arthrotomy to evaluate the results. The fitting of the scaffold in the cartilage defect and the strength of the fixation was analyzed. The navigated defect geometries (height, width) were compared with the cartilage defect shape from the cadaver knees.

Results

With the help of the OrthoPilot navigation system and the CDM module, the arthroscopic implantation of bioresorbable scaffolds for the MACT is feasible.

The cartilage defect at the medial femoral condyle was assessed arthroscopically three times by three different examiners. The defect geometry obtained with the navigation device varied from the defect sizes in the cadaver knees by ± 1 mm, which is inside the navigation system accuracy of ± 1.5 mm. The results were checked regarding the reproducibility of the defect parameter acquisition. The data show that the arthroscopic cartilage defect assessment

Fig. 3 Arthroscopic implantation of the navigation guided customized scaffold. After preparation, **a** the scaffold was implanted arthroscopically and fixed with bioabsorbable pins (**b–d**)



using the CDM module is easily reproducible even between several examiners (Table 1).

After the mapping of the cartilage defects, the camera was adjusted and calibrated. Then the defect shape was successfully transferred to the MACT scaffolds with a

Table 1 Results of the arthroscopic cartilage defect mapping

Executor	Trial	Circ. (mm)	Area (mm ²)	Max. H. (mm)	Max. W. (mm)
P.A.	1	32	64	9	12
	2	34	77	9	13
	3	33	72	8	13
J.Z.	1	33	68	9	13
	2	34	70	9	13
	3	34	73	9	13
N.G.	1	33	72	9	12
	2	33	69	9	12
	3	34	74	9	13

The defect was assessed three times by three different examiners. The defect geometry mapping showed a high accuracy for the defect parameter acquisition and a good reproducibility between several examiners

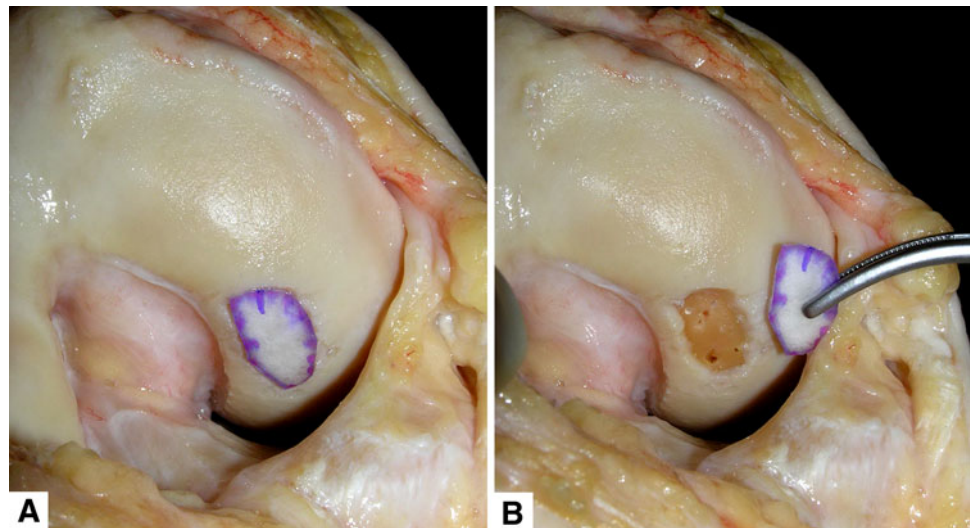
sterile skin marker in all cases and cut afterwards following the skin marker lines.

After the preparation, the scaffolds were arthroscopically implanted in the cartilage defects. To introduce the matrix, the scaffolds were introduced in the knee joint via an applicator tube with a fleece grasper. After positioning of the scaffold, a drill guide was inserted through the anteromedial portal. Then a k-wire was drilled into the subchondral bone perpendicular to the scaffold. After removal of the k-wire, the scaffold was fixed with bioresorbable pins (FR736 resorbable pin for scaffold fixation, B. Braun-Aesculap, Tuttlingen, Germany), which were cut into the correct length of about 30 mm. The heads of the pins were under the level of the surrounding native cartilage.

The number of pins needed for the fixation of the scaffold depends on the size and shape of the defects.

To evaluate the results of the defect assessment and the arthroscopic implantation of the scaffold, the knee was opened with an arthrotomy. The defect size was measured and the results were compared with the navigated defect size parameters. The defect geometry obtained with the navigation device varied from open measured defect sizes by ± 1 mm, which is inside the navigation system accuracy

Fig. 4 Postoperative evaluation. After the arthroscopic implantation, the scaffold showed an exact fitting and a strong fixation in the defect



of ± 1.5 mm. Consecutively, the navigated and prepared scaffold fitted exactly into the cartilage defect. (Fig. 4) The fixation of the matrix was stable. As the heads of the fixation pins were under the level of the surrounding native cartilage, no chondral damage on the opposite side of the defect or other pin related side effects could be detected.

Discussion

The study shows that the arthroscopic implantation of biodegradable scaffolds for the MACT is possible. Especially large full thickness chondral defects at the medial or lateral femoral condyle can be treated by the arthroscopically performed MACT in the future. One condition for a successful arthroscopic treatment of cartilage defects is the correct assessment of the geometry of the chondral lesions. Erggelet et al. [6] used a specific scaled needle which can be inserted percutaneously in all necessary angles. However, more complex defect shapes can not be mapped correctly by this method. An advantage of the CDM module of the OrthoPilot is the chance to measure the depth of the defects. As there are some deep osteochondral defects the navigation can help to analyse the need of bone grafting under the chondrocyte transplantation.

Niemeyer et al. [13] showed that arthroscopic and open assessment of size and grade of cartilage defects of the knee differ. Particularly smaller defects are overestimated. However, a correct and reliable defect assessment and mapping are crucial for choosing the appropriate cartilage therapy like microfracturing, osteochondral transplantation or chondrocyte transplantation.

So the navigation system is a useful tool to assess all important parameters of the cartilage defects to plan the operative procedure and to perform a customized therapy. A prior study showed that navigation can detect and measure

exactly the cartilage defect sizes of different geometries on casting patterns and test templates [1]. The present study shows that also under arthroscopic conditions the CDM module can map a cartilage defect correctly and the results are easily reproducible. The accuracy was within ± 1 mm of the clinically relevant level. As the navigation system is easy to handle, the arthroscopic assessment of the cartilage defect was estimated with an additional surgery time of 10 min.

Besides the chondral defect mapping, the CDM module allowed for the precise transfer of the navigated cartilage defect geometries for exact size preparation of the tissue engineering scaffolds. No additional intraarticular manipulation is needed for a correct fitting of the transplant. Also cartilage defects of complex shape can be assessed and transferred directly to the tissue engineering scaffold for an optimal customized therapy. The previous methods of measurement only allowed for the treatment of circular- and oval-shaped defects with the arthroscopic MACT [14]. Navigation is a useful tool to treat larger and deeper full thickness cartilage defects arthroscopically.

As known from other surgical procedures like ACL reconstruction, arthroscopic treatments reduce postoperative side effects of open approaches like adhesions and arthrofibrosis. Erggelet et al. [5] claimed that 26% of the procedure related problems of the ACT can be contributed to arthrotomy. Our study shows the feasibility of performing an arthroscopic MACT. To introduce and manipulate the ACT scaffolds properly, the instrumental portal should be made in a perpendicular direction to the defect area. The ACT matrix should be marked, grasped outside and introduced into the knee in the correct orientation to facilitate the positioning in the defect and to avoid unnecessary intraarticular manipulation with the tissue engineered scaffolds. The fleece grasper should have a kind of anchor at the tip to keep the scaffolds in the correct position during the application of the fixation system.

The fixation device is an important issue for a successful MACT. Hunziker et al. [9] reported a high failure rate after suturing the scaffold to the cartilage borders of the defect. For an arthroscopic approach of the MACT, Erggelet et al. [6] first described the technically demanding transosseous anchoring fixation. Zelle et al. [21] evaluated the biomechanical properties of three different fixation techniques for MACT. Compared to the transosseous anchoring and the suturing of the matrices, the pin fixation showed the best results. However, the fixation pin angle is crucial as a tilted pin contributes to increased joint compression forces [8]. In our study, the fixation of the scaffold with pins was feasible as long as a perpendicular access is possible. As the heads of the pins are under the level of the surrounding native cartilage, no adverse side effects to the opposite cartilage were seen.

In conclusion, the present study shows that the arthroscopic implantation of a biodegradable scaffold for the MACT is possible by the use of a navigation system. The correct defect management is an important requirement for successful arthroscopic chondrocyte transplantation. Navigation can help to choose the appropriate cartilage therapy and to assess the cartilage defect geometry precisely. So chondrocyte transplantation can be planned and the defect shape can be exactly transferred to the precultured tissue engineering product for a customized therapy. Therefore, navigation is an important tool to accomplish and optimize the arthroscopical MACT.

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