



Ultra-Fresh Osteochondral Allograft Transplantation Supported by Artificial Intelligence Algorithms - Case Report of a 14-Year-Old Patient

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Abstract

Surgical treatment of cartilage surface lesions is similar to tumor surgery in many ways. Depending on the extent, depth, and nature of the lesion, different pathways can lead to a solution. In our case, we performed an “ultra-fresh” osteochondral allograft transplantation due to an extensive osteochondral lesion in the lateral femur condyle of a 14-year-old patient. One of the main limitations of this process is to create a precisely sized and fitting graft, and thereby establishing the best congruence possible. In order to achieve this, MRI-based artificial intelligence algorithms were developed and this was used for donor-recipient matching. Postoperative follow-up of the patient was performed according to current international protocols. Although we do not have long-term experience with the use of artificial intelligence in this form, we believe that matching the most appropriate donor-recipient pairs during transplantation may affect the long-term outcomes of surgery.

Keywords: Knee; Cartilage; Ultra-fresh osteochondral allografts; Artificial intelligence; Deep learning

Introduction

There are two types of surgical treatment methods concerning the therapy of cartilage surface defects. One effort is to try to biologically restore the destroyed cartilage surface and the underlying bone, using various cartilage resurfacing techniques. Such techniques include procedures that promote natural regeneration: Biodegradable matrix implantations, cartilage resurfacing with cell culture transplantation, and implantations of osteochondral autografts and allografts [1]. All of these techniques are used to achieve a joint sliding surface of the same or a similar quality as the original, but the common feature of all these techniques is that they are only suitable for the treatment of focal lesions. Regarding the limitations of their size, it is only possible to treat small and superficial lesions in this manner. In addition, good quality of the surrounding intact joint surfaces is also a requirement [2,3].

When damage to the cartilage surface is extensive, and most of the joint surface has severe arthritic changes, endoprosthetic options may provide the best solution.

There remains a fairly wide, unresolved gap between the above mentioned two main surgical treatment methods. In the case of the knee joint, a significant group of patients have extensive unicompartamental damage that no longer allows the use of the mentioned biological surfacing methods, but due to the patient's age, severity of the lesion, and many other considerations, arthroplasty is too premature due to long-term complications. For these cases, we currently only have compromise solutions.

Based on experience in literature thus far, homologous cartilage-bone tissue transplantation and osteochondral allograft transplantation provide a solution for the biological treatment of extensive and deep focal defects and the formation of a hyaline cartilage-quality surface in the area of damage. The practice to date, mostly in North America, uses osteochondral allograft blocks acquired from the 10-day to 3-week age, provided by a tissue bank [4]. Observations show that the transplanted

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Figure 1: Preoperative three-directional weight bearing radiographs and MRI images in three different axes (T1 and T2 weighted) of the patient's knee.

hyaline cartilage cells in osteochondral allografts demonstrate only a 50% survival rate, in the optimal case, due to the length of time between donation and implantation [7]. In the long term, this leads to degeneration of the newly formed surface.

Basic research results have shown that by reducing the time between graft removal and implantation, cell survival can be improved [5]. Based on all this, in 2009, we introduced the surgical technique of implanting so-called ultra-fresh osteochondral allografts at Uzsoki Hospital, Department of Orthopedics and Traumatology [6]. In this case, the transplantation takes place within 24 h to 36 h of graft removal. Excellent functional results and cell survival rates were observed based on the past 11 years of practice, clinical and radiological findings, follow up arthroscopies and histological analysis of biopsies [6]. In current practice, donor-recipient pairing as well as the preparation and fitting of the graft to the defect are based on the visual and professional judgment of the operating surgeon. It would be a major technical advance in surgery if the geometry and size of the recipient's defect surface and underlying bone lesion could be more closely matched to the donor parameters of the transplanted graft. Therefore, by improving congruence, there would be less secondary degenerative progression, which compromises the long-term outcomes of the transplantation. Given the good graft survival experience gained over the past eleven years of practice, with the aforementioned technical support of surgery, the indication could be extended beyond the current relatively rare massive osteochondral lesions to the more common unicompartamental problems.

The MRI data thoroughly portrays the size and shapes of the defects, cartilage quality, and congruence of the damaged joints. When this is compared with the donor parameters, it not only allows a quick and optimal donor-recipient pairing, but also gives the opportunity to extract multiple blocks using both donor joints from a single donation.

Case Presentation

A 14-year-old judoka (judo athlete) boy fell onto his left knee during practice, resulting in significant knee complaints. X-ray and MRI examination revealed an extensive OCD-like lesion on the lateral femur condyle (Figure 1).

Considering that the lesion was extensive in both diameter and depth, osteochondral allograft transplantation was chosen as the best treatment method. In our institute, we used an artificial intelligence algorithm to achieve optimal donor selection for the ultra-fresh allograft transplantation. In order to optimize the tibia-femoral congruence, the appropriate donor for surgery was found with the help of an artificial intelligence algorithm based on a deep convolutional neural network [7]. Initially, we manually segmented

the cartilage on the 500 MR images with the appropriate sequence, and then later used semi-automatic methods. We used these to train our artificial intelligence algorithm. For segmentation, we used a TRUFI sequence, which is more suitable for training than the one used in daily practice [8].

Surgery was performed from the lateral parapatellar approach with detaching the tibial tuberosity and completely retracting the patella for easier access. We used Arthrex's BioUni instrumentation for sizing and the precise shaping of the graft, which allowed us to achieve a "press-fit" fixation on the recipient side. Following the operative approach, as a first step in the surgery, we removed the osteochondral fragment from the weight-bearing surface of the lateral femoral condyle and refreshed the bone base. After sizing, the recipient site was prepared using the available tools and templates (Figure 2).

The donor femur was then properly secured, followed by the preparation of the graft to the appropriate size and congruence using the cutting templates. AI was used for the exact localization of the donor area. Selection of the recipient was based on the comparison of the MRI dataset of potential recipients on the waiting list and the donor's removed femur distal end, matching them according to the optimal corresponding shapes. Artificial intelligence also determined the location of where to harvest the graft from the donor knee to attain the most accurate curvature. Based on our measurements, this was the marked central part of the weight-bearing area of the medial femur condyle (Figure 3).

As a final step of the operation, the donor osteochondral graft was tapped into place at the recipient site with a tamp, achieving such a secure press-fit fixation, that no other implant was needed for further fixation (Figure 4). The detached tibial tuberosity was fixed with 2 partially threaded cancellous screws and the wound was closed layer by layer.

In the aftercare, CPM was applied for the first week after surgery and full range of motion exercises were allowed. Regarding weight bearing; only toe-touch weight bearing was allowed for the first 2 weeks and then the load was gradually increased at 2-week intervals (30 kg, 50 kg, and 70 kg). X-rays and MRI scans were taken at 6 and 12 weeks postoperatively to monitor graft incorporation (Figure 5, 6). After 12 weeks, a full body weight-bearing (110 kg) was allowed. After the third postoperative month, the patient's knee flexion was 125 degrees and his muscles were also nearly equivalent to the contralateral side (Figure 7).

Discussion

Indicative and technical aspects of fresh osteochondral allograft

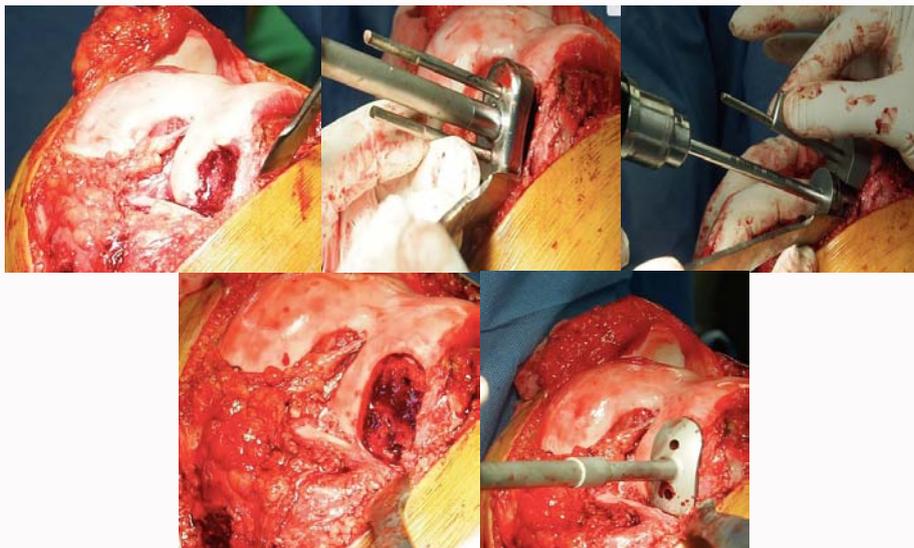


Figure 2: Isolation of the defect on the lateral femoral condyle and preparation of the recipient site.

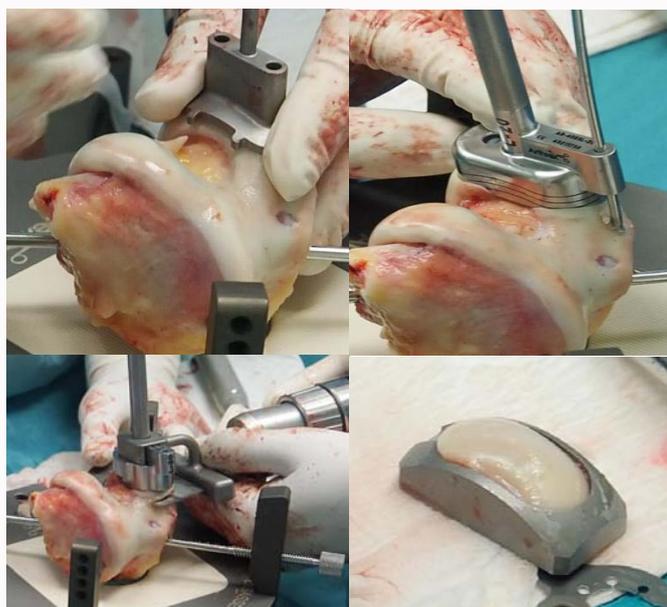


Figure 3: Preparation steps of the donor site.



Figure 4: Intraoperative photo and postoperative radiographs following the transplantation, which show the appropriate filling and fixation of the osteochondral fragment into the recipient site.

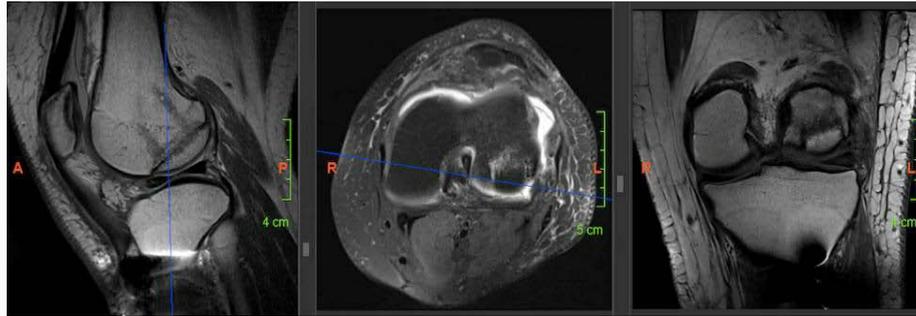


Figure 5: MRI images in three different axes at 6 weeks.

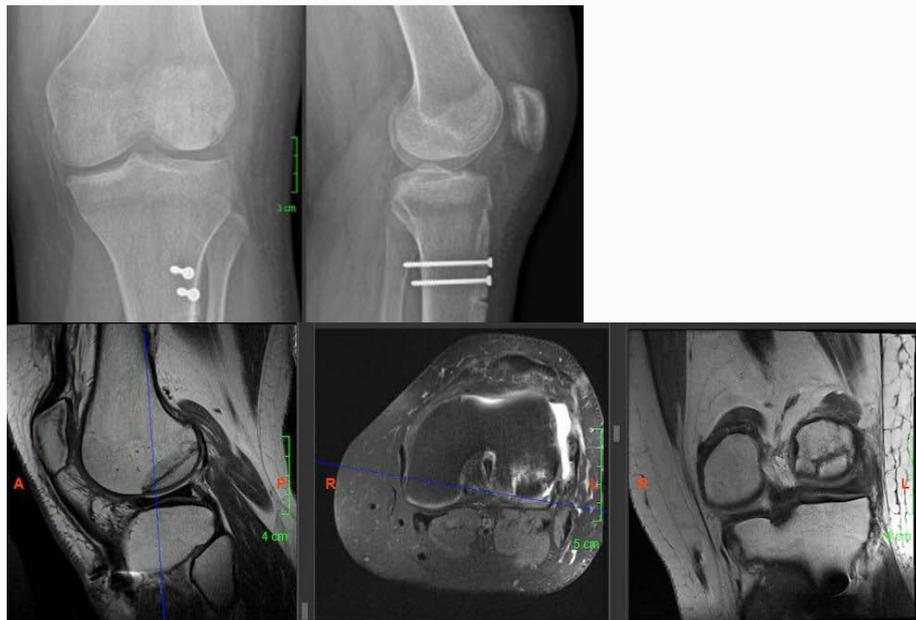


Figure 6: AP and lateral radiographs and MRI images in three different axes at 12 weeks.



Figure 7: Photos demonstrating of range of motion at 12 weeks follow up.

transplantation have been accepted in the literature by international consensus [9,10]. Current recommendations consider it appropriate as a structural biological surface replacement for medium and large-size focal osteochondral defects, but draw attention to limited chondrocyte survival that can lead to long-term cartilage deterioration [10]. According to several reports, cell survival can be improved by reducing the time between graft removal and implantation [5]. This has been confirmed in the past 11 years in our department, as we have followed-up on the results of the so-called ultra-fresh osteochondral

graft transplantations, which were performed within 48 h of removal [11,12].

This raises the possibility of biological replacement of extensive unicompartamental surface lesions, yet also poses significant sizing and congruence problems.

The MRI-based artificial intelligence we developed provides an opportunity to compare the geometric characteristics of the graft obtained for donation with the MRI data of patients with

extensive unicompartmental cartilage surface damage waiting for transplantation (kept on a waiting list). Initially, the manual segmentation TRUFI sequence training [8] proved to be suitable for the development of AI, which provided a better-quality image of the distal end of the femur, than expected by manual segmentation. For the surgery in the case report, donor-recipient matching was obtained by segmenting data from 500 MRI scans. AI also pinpointed the best fitting surface region on the donor knee to be used for repair of the defect. In the aforementioned case report, a specific part of the medial femoral condyle of the donor knee presented the best geometric similarity to the defect on the recipient's lateral femoral condyle. This suggests that in an optimal case, one donor knee may simultaneously provide more grafts for more recipients in the future.

The technical implementation of allograft implantation remains a demanding surgical task that requires the support of well-standardized instrumentation. In our case, the Arthrex BioUni instrumentation was perfectly suitable for this, but most likely other instrumentation kits could also be used that allow for the precise preparation of the recipient site defect into the intact area and provides a press-fit fixation of the graft from the donor site, which is of the same shape and of the required thickness.

By its nature, the performance provided by AI depends on the amount of data input used for the learning process. In our case, the processing of the 500 MRI's provided adequate surgical support. By increasing the number of segments, accuracy can be further improved. In terms of the data used for segmentation, AI further developed using sequences that better reflect cartilage quality can be a major diagnostic and follow-up tool for orthopedic surgery [13].

In addition to the above, deep convolutional neural network based artificial intelligence algorithms used in the analysis and data comparison of cartilage surface geometry can further aid us in the reconstruction of articular fractures as well as in endoprosthesis design processes.

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