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Three-dimensional printing improves osteochondral allograft placement in complex cases

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Abstract
The use of three-dimensional (3D) printing has seen a vast expansion over recent years, with an increased application for its use in orthopaedics. This report details the use of 3D printing technology to aid in the treatment of a medial femoral condyle osteochondral defect in a 26-year-old female who had previously undergone a failed autograft procedure. A preoperative computed tomography scan of the knee and chondral defect was used to generate a 3D printed, one-to-one scale replica of the distal femur. This replica was then used to size a patient-specific allograft plug for the osteochondral transplantation procedure. The patient recovered well, and 1 year postoperatively the allograft was well incorporated into the medial femoral condyle and healed. This report illustrates the advantages of using a 3D printed model to allow for tactile feedback and improved visualization that will allow for improved understanding of complex surgical procedures.
Level of evidence V.

Keywords 3D printing · Osteochondral allograft transplantation · Osteochondritis dissecans · Preoperative planning

Introduction

Three-dimensional (3D) printing based on computed tomography (CT) scans has become an increasingly useful tool [14, 17]. While initially there was not much use for 3D printing in orthopaedics [14], preoperative printing of bony structures has become a valuable tool for generating patient-specific templates[13], instrument guides[3], and preoperative navigation and planning [9]. These models have also allowed for a better understanding of complex pathology [3]. In this case report, we apply this technology to size an osteochondral plug for osteochondral allograft transplantation (OCAT) procedure to treat a medial femoral condyle osteochondral defect.

The aetiology of osteochondritis dissecans (OCD) lesions is poorly understood, yet they are among the most common causes of knee pain and dysfunction in young adults, with the highest incidence found in 20- to 30-year-old males [10, 16]. Evidence suggests that OCD lesions in adults are more commonly the result of unhealed juvenile lesions rather than arising de novo [7]. Due to the chronic nature of OCD lesions in adults, these lesions are often larger in diameter, more advanced and more complex than lesions in younger patients. When performing OCAT for OCD lesions, it is important to obtain excellent fit of the allograft plug, flush with the patient's condylar surface [8, 10]. Therefore, careful contouring of the allograft plug is necessary to match the patient's condylar defect [12].

To our knowledge, this is the first case report which describes using 3D printing in orthopaedics to assist with osteochondral allografting in a patient with a history of prior failed grafting procedures. The use of a 3D model results in superior visualization and understanding of the OCD lesion, which ultimately may result in superior graft placement and patient outcomes.

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Case report

The patient was a 26-year-old female with a longstanding history of left knee pain, and a prior diagnosis of an OCD lesion of the left medial femoral condyle. Her OCD lesion was treated at an outside institution with an Osteochondral Autograft Transfer System (OATS, Arthrex, Atlanta GA) procedure. The patient did well initially; however, over the subsequent years she developed recurring pain over the medial knee, especially with squatting. Upon examination, she had minimal swelling of the knee with pain upon loading of the medial compartment. Magnetic resonance imaging revealed deterioration of the previous autograft. A CT scan was then performed, which demonstrated a 2.4 × 1.9 cm osteochondral defect with 2 mm of depression (Fig. 1). Treatment options included nonoperative treatment, a high tibial osteotomy, unicompartmental arthroplasty, and an OCAT procedure using a fresh allograft. Due to her refractory pain and troubles with daily activity, operative treatment with OCAT was chosen. Informed consent was obtained from the patient.

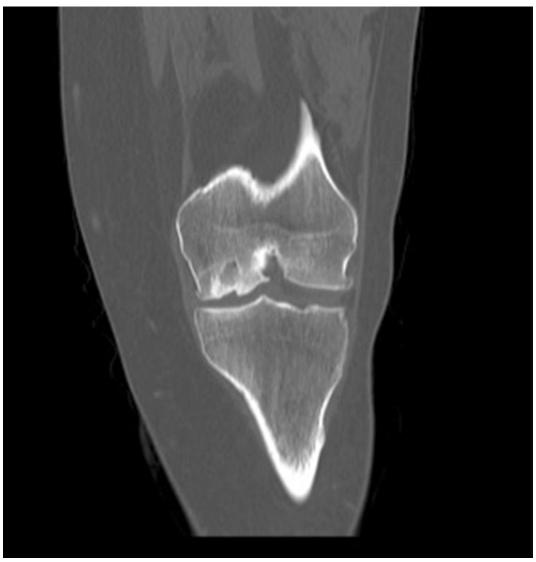


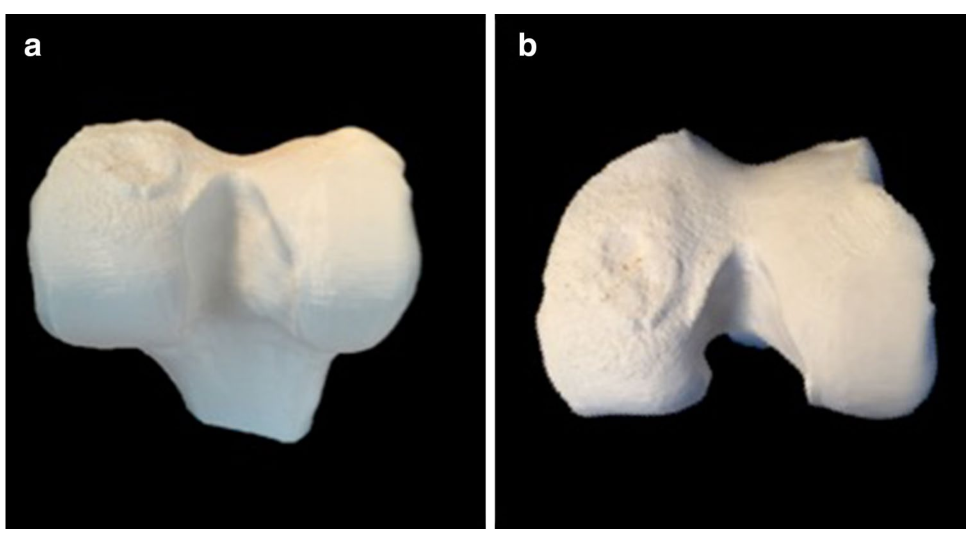
Fig. 1 Coronal computed tomography scan taken prior to osteochondral allograft transplantation demonstrating the ~ 2.4 × 1.9 cm osteochondral defect of the medial femoral condyle of the left knee

Prior to the surgery, the previous CT imaging was used to create a 3D reconstruction image using Materialise Mimics and 3-matic software (Plymouth, MI). This 3D reconstruction image was then used to print a one-to-one scale replica of her distal femur using a fused deposition modelling 3D printer (Fig. 2). This model was used in preoperative planning as a reference of the width, depth, and orientation of the defect. It was used to identify the exact location of the defect and as a reference for where the osteoarticular allograft harvest should be obtained.

On the day of surgery, a diagnostic arthroscopy of the knee was then conducted and confirmed the presence of the osteochondral defect on the medial femoral condyle measuring ~ 2 × 2.5 cm. The patient then had an open approach with a medial parapatellar arthrotomy to perform the OCAT procedure.

The core size was determined to be 22.5 mm. The sizer was placed over the lesion and a guide pin drilled into the centre of the lesion. A size-matched core reamer was then used over the guide pin and bored to a depth of ~ 10 mm. The 12 o'clock position was marked surrounding the bore hole. A site dilator was then used and the depth of all four quadrants was determined. The 3D model was then placed on an accessory mayo stand to allow for reference on location of harvest of the allograft. The patient's articular defect corresponded quite well with the 3D model. The lesion was

Fig. 2 Three-dimensional printed one-to-one scale replica of the patient's distal femur



not central to the medial femoral condyle. The site of injury was cross-referenced with the 3D model at this time. Preoperative measurements obtained from the model were used to mark the allograft tissue. References from the superior margin off the articular surface as well as the notch of the femur were used to best identify the central location of the lesion. Using this method, we were able to more accurately harvest the donor graft from the corresponding area on the medial femoral condyle.

The allograft was then placed into a cutting jig, and a size-matched donor reamer was used to obtain the donor plug. The bed of the recipient site was then prepared by drilling multiple holes to stimulate bone bleeding. The graft was then inserted into the recipient site, aligning the 12 o'clock marks on the graft and recipient. The graft obtained great fit and was flush with the native articular cartilage (Fig. 3).

The patient experienced no complications and was made non-weight bearing for 6 weeks, with use of a continuous passive motion machine for ROM progression. She began physical therapy 1 week after surgery for stretching, ROM and strengthening. At 4 weeks postoperatively, she had a ROM of 0°–125°, with mild pain over the medial joint line. At 4 months, she was progressed to nonimpact, aerobic exercises and then to low impact aerobic exercises at 6 months. At 12 months postoperatively, radiographs indicated excellent incorporation of the allograft (Fig. 4a, b). She had full ROM and no tenderness over the medial knee. At 18 months postoperatively, her ROM remained full with no tenderness to palpation or instability noted on examination of the knee.

Discussion

The goal of OCAT is to improve joint function, allowing the patient to ambulate comfortably with everyday activity and increase the potential for athletic activities [2]. Chu et al. found that 85% of patients receiving OCAT for isolated focal lesions of the knee had good to excellent results at 6 years post-surgery using the Merle d'Aubigne and Postel scale [5].

While most studies suggest favourable results, the success of the surgery depends significantly on the fit and flushness of the allograft plug, and how well the patient assimilates the tissue [6, 18]. Koh et al. demonstrated that leaving an allograft 0.5–1.0 mm proud resulted in 50% more contact pressure to the graft relative to a flush fit [11]. This additional contact pressure has been shown to result in chondrocyte death [12]. If the graft protrudes above the surface of the condyle, impaction may be used to drive the plug in; however, this may lead to chondrocyte apoptosis [4, 15]. Thus, attaining a flush fit without significant impaction is critical to successful graft incorporation.

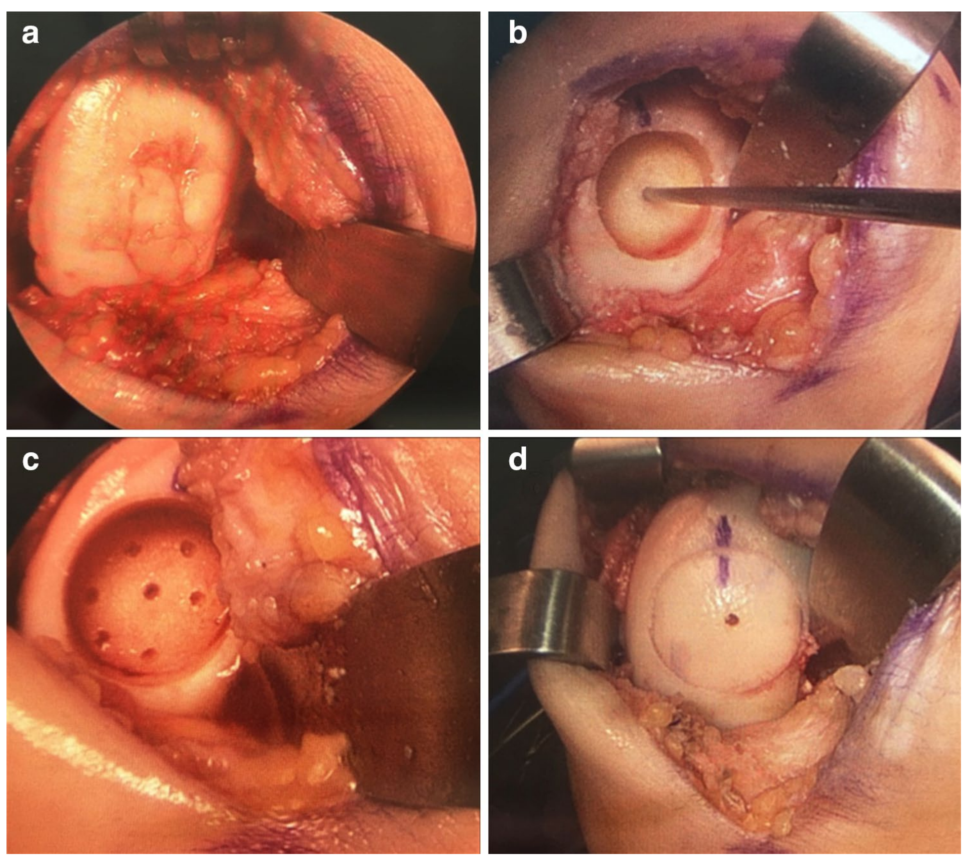


Fig. 3 Intraoperative pictures of the osteochondral allograft transplantation procedure. **a** Demonstrates exposure of the osteochondral defect measuring ~ 2.4 × 1.9 cm. The lesion was then removed (**b**) using a core reamer and guide pin anchored in the centre of the lesion. Holes were drilled into the subchondral bone (**c**) to stimulate bony bleeding to encourage graft incorporation. **d** Demonstrates excellent fit of the allograft

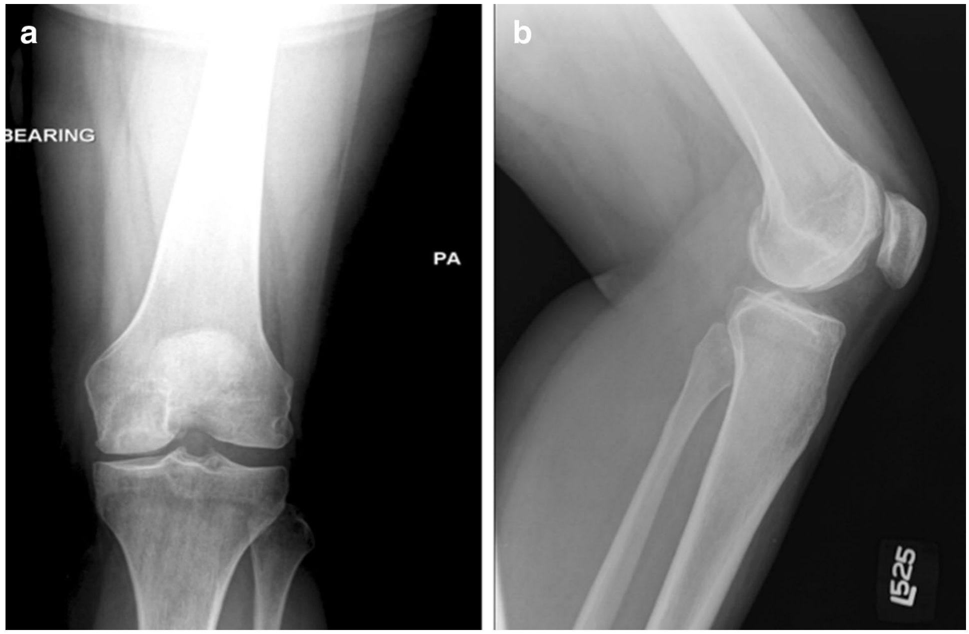


Fig. 4 One-year postoperative radiograph (posterior-anterior [**a**] and lateral [**b**]) demonstrating excellent incorporation of the allograft into the medial femoral condyle

In cases with complex anatomy or pathology, 3D models provide surgeons with a live model that can be manipulated while planning, rather than studying static two-dimensional images [14]. It also offers the unique tactile feedback that can aid the surgeon in better understanding the pathology or tissue defect.

The patient's case was complex in that it was complicated by the size of the lesion and history of a previous failed OATS procedure, which created abnormalities with imaging and the potential for surgical obstacles. It is not known why the autograft failed; however, it is possible it failed to incorporate because of improper fit.

For lesions over 2 cm in diameter, OCAT has been shown to be the preferred method of treatment over OATS, microfracture, or simple debridement [18]. However, these large complex lesions tend to be more difficult operatively to fix and there is room for improvement with the additional understanding imparted by the 3D models. The models allow for improvement in our harvesting approach compared to using two-dimensional CT references. In our case, we were able to identify that our patient's lesion was not central in location, which is commonplace. This allowed us to better match the patient's cartilage contours by taking our graft from a location more similar to the location of injury. This allowed for a more anatomical contour of the graft when implanted into the patient.

This unique approach to OCAT using 3D printing of the distal femur prior to surgery allowed to determine the precise location and size of the lesion, providing a seamless transition of allograft from donor to recipient site with minimal impaction. This approach helps surgeons to have a better preoperative grasp of the lesion allowing them to match the allograft contour with that of the patient's femoral condyle while minimizing tourniquet time, which has been shown to be beneficial to postoperative outcomes [1].

Conclusion

3D printing continues to advance as a technology and proves to be useful in various medical applications. Here, we document the novel use of this technology to aid in a case with increased complexity due to the previously failed grafting procedures. For cases with complex pathology, the application of 3D printing allows surgeons a better understanding of the anatomy, which can lead to a more efficient procedure and higher likelihood of patient success.

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Compliance with ethical standards

Conflict of interest No authors have any financial disclosures.

Ethical approval The local institutional review board approved this study (IRB: Henry Ford Hospital, Detroit, MI).

Informed consent A signed formed consent was obtained from the patient allowing publication of this case report.

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