# A Nondestructive Autograft Extraction Method for Autologous Osteochondral Transplantation


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## ABSTRACT

Osteoarthritis is the degeneration of articular cartilage and subchondral bone, often leading to pain, joint stiffness, and disability. Post Traumatic Osteoarthritis (PTOA) develops after a joint injury. Such injuries can damage the articular cartilage and/or the bone, changing the mechanics of the joint and making it wear out more quickly. Mosaicplasty is a well-established technique for cartilage repair for osteochondral cartilage transplantation for PTOA. Due to current technological limitations, harvesting large grafts is not practical. The success of harnessing a larger and complex shaped graft to replace the damaged osteochondral area lies in effective extraction of the cartilage-bone graft from the donor site. Currently, no method exists to perform this procedure. So, we have proposed a novel bone removal mechanism to harvest a personalized autologous graft irrespective of its shape and size. Our method involves drilling/milling the profile around the region of interest from a non-weight bearing site according to the damaged cartilage profile and slicing off the bottom part of the graft from the bone using a flexible string saw approach like Gigli saw used for bone amputation. We have designed a mechanism which inserts the flexible saw parallel to the transverse plane and slices the graft parallel to the coronal plane to extract the graft.



## Keywords

Osteoarthritis, Autografting, Osteochondral Cartilage, Post Traumatic Osteoarthritis, Mosaicplasty, Cartilage Extraction.


## 1. INTRODUCTION

Osteoarthritis (OA) is the degeneration of articular cartilage and subchondral bone, often leading to pain, joint stiffness, and disability [1]. It is a well-known degenerative joint disease characterized by biochemical and molecular changes within the tissue that result in progressive erosion of the articular cartilage [2]. For more than 90% of the cases, there is no apparent etiology or initial cause for the disease and there appears to be a direct relationship to aging. This form of the disease is known as primary osteoarthritis. When the disease occurs in younger patients with a specific cause like traumatic injury or systemic metabolic disorders like obesity, then it is referred to as secondary osteoarthritis. Age-dependent changes in extracellular matrix components result in decreased mechanical strength and resiliency of the cartilage tissue. Although the relationship to age and traumatic injury has often led to the oversimplification of the disease as a function of “wear and tear”, research has shown more complex cellular pathogenesis. Post Traumatic Osteoarthritis (PTOA) develops after a joint injury. The injury may be in the form of fracture, cartilage damage, acute ligament sprain, or chronic ligamentous instability (or combination of these) [1]. Such injuries shown in Figure 1 can damage the articular cartilage and/or the bone, changing the mechanics of the joint and making it wear out more quickly.

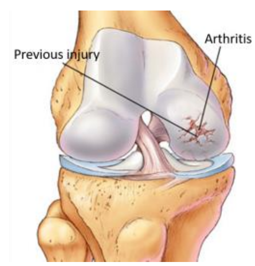
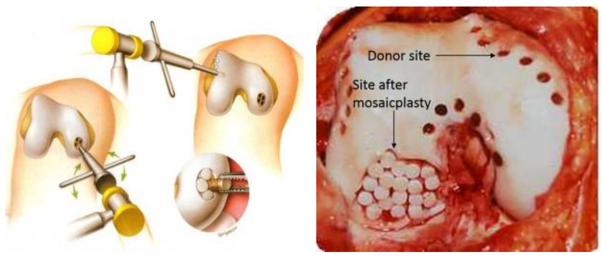



**Figure 1. Graphical representation of osteochondral (bone and cartilage) damage/osteoarthritis [3]**

Mild PTOA can be treated with weight loss, low impact exercise, strengthening of the muscles surrounding the joint, and non-steroidal anti-inflammatory medicines. Arthritic joints can also be injected with corticosteroids to decrease inflammation or with hyalgan, which acts like an artificial joint fluid. These measures provide symptomatic relief but do not slow down or reverse the cartilage damage. Nearly 27 million adults aged 25 or above have a clinical diagnosis of OA [4]. Among those, PTOA affects 5.6 million people and is the cause of about 12% of osteoarthritis of the hip, knee, and ankle in the United States [5]. When osteoarthritis progresses to the point that conservative measures are no longer effective, then surgical treatments are often performed. Surgical treatment may include debriding, reconstructing, or replacing the worn out joint surfaces. There are numerous surgical procedures aimed to repair or regenerate osteoarthritic lesions which include microfracture, autologous osteochondral cylinder transplantation (mosaicplasty), artificial bone graft substitutes and cell-based repair techniques such as autologous chondrocyte implantation (ACI)[6]–[8]. Compared to mosaicplasty, ACI is more expensive,




**(a)** **(b)**

**Figure 2. (a) Steps in mosaicplasty and (b) site after mosaicplasty [9].**

requires two procedures and an open arthrotomy [10]. The microfracture technique is typically used for small defect areas while osteochondral transplantation is used for larger cartilage defects [6] and has advantages over microfracture.

For osteochondral transplantation, plugs of healthy cartilage with subchondral bone are extracted either from the joints of a cadaver (allografts) or from a non-load bearing area of the patient (autografting) and inserted into the arthritic defect (in case of mosaicplasty) shown in Figure 2 (a) and (b). Unlike allografts osteochondral autograft transplantation (OAT) uses the patient's own tissue eliminating any risk of infectious disease transmission [11]. Both cartilage and bone are harvested from the donor site, so OAT has the advantage of filling osteochondral defects, making OAT an option in treating smaller osteochondritis dissecans lesions [12].

For mosaicplasty, combination of grafts are able to resurface 80-100% of the damaged area [12]. Although, mosaicplasty is a well-established technique for cartilage repair, due to current technological limitations, harvesting large grafts is not practical. The success of harnessing a larger and complex shaped graft to replace the damaged osteochondral area lies in effective extraction of the cartilage-bone graft from the donor site. Currently, no method exists to perform this procedure.

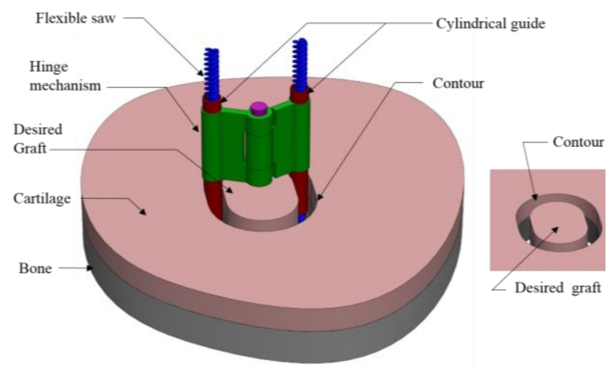
In this paper, we are proposing a novel bone removal mechanism to harvest a personalized autologous graft irrespective of its shape and size.

**Figure 3. Commercially available Gigli saw which is less flexible**

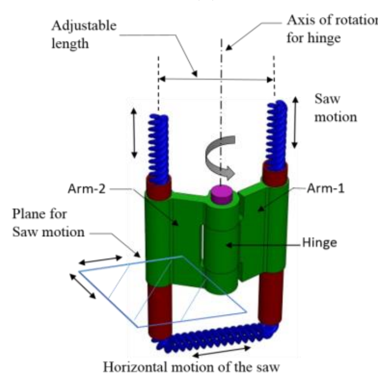
## 2. Method

There are two components to our approach: 1) milling the profile around the region of interest, and 2) extracting the graft by using the proposed mechanism. The path drilling/milling can be performed using orthopedic robots such as Robodoc [13], Acrobot [14], Caspar [15], Mako [16] or a bone attached orthopedic robot HyBAR [17]. Potential donor sites must be in non-weight bearing areas. The difficulty in extracting donor grafts for autografting lies in separating the bottom surface of the graft from the donor site. This problem does not exist for allografting because the cadaver tissue can be completely sliced. To accomplish this, our mechanism involves converting the typical saw motion from the transverse plane to coronal plane. We have used the concept of Gigli saw approach often used for amputation. But we are avoiding commercially available Gigli saw (Figure 3) due to its less flexible property which will hinder sharp bending in the cylindrical guide that we are using in our device.

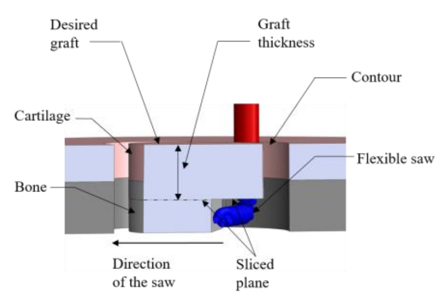
For the proposed method there are two challenges: 1) to insert the flexible saw parallel to the transverse plane and slice the graft parallel to the coronal plane, and 2) to deal with irregular shaped contour. To optimize the travel path for the saw while having




**(a)**




**(b)**



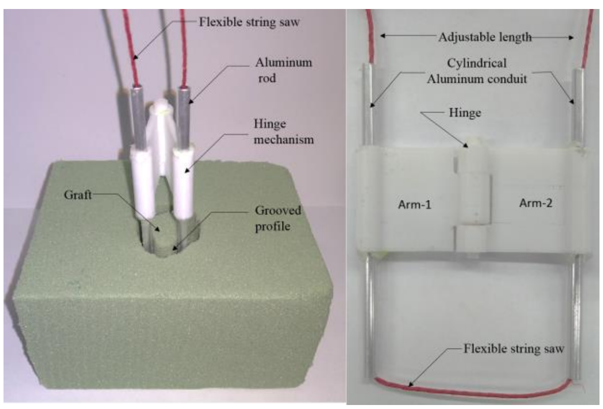

**(c)**

**Figure 4. CAD model of (a) donor tissue removal setup, (b) detailed view of flexible string saw mechanism, and (c) cross-section of the donor tissue while being sliced.**

motion parallel to coronal plane the strings must be parallel to each other throughout the procedure. To achieve the required motion configuration the saw is guided through two hollow cylindrical guides parallel to each other, as shown in Figure 4 (a). The two cylindrical guides are positioned along the contour path. These two cylinders are rigidly attached at the end of two arms which are linked with a hinge shown in Figure 4(b).

The hinge mechanism was used to allow varying distance between the two cylinders (Figure 4 (b)). Since the two arms of the guide can rotate about the hinge independent to each other the two cylinders can follow a complex shaped contour. This gives the flexibility to move the string saw along a contour with an irregular shape. It also ensures parallelism between the cylindrical guides at all time. It is important to have the two cylinders parallel to each other and perpendicular to the coronal plane (i.e. slicing plane) to follow the contour properly and extract a graft with a perpendicular edge. Since the receiving site has a perpendicular edge this will ensure a better fit for the extracted graft. The string saw will reciprocate in between guided cylinders and as a result, the bone will be sliced along the coronal plane as shown in Figure 4 (b) and (c). Figure 4 (c) shows how required thickness of the graft can be maintained if the string saw is reciprocating without changing the depth of its motion.

# 3. RESULTS




**(a) (b)**

**Figure 5. A foam removal experiment using the prototype showing (a) experimental setup after precision milling of donor profile and (b) prototype device**.

A proof-of-concept prototype was fabricated using a 3D printed arm-hinge mechanism and two aluminum conduits as a guide. A simple slicing experiment was performed on a floral foam using the prototype as shown in Figure 5 (a) and (b). The prototype could slice the desired thickness of graft producing a flat surface underneath, despite the profile being an irregular shape (e.g. non-circular, oval shape). It was possible to deal with an irregular profile and harness the graft because the hinge mechanism permitted the guides to move freely while remaining parallel, regardless of its shape.

# 4. DISCUSSION

The results show that the prototype can transfer reciprocating saw motion from the transverse plane to the coronal plane and harness a graft of desired thickness. At the same time the hinge mechanism including two arm provides the flexibility to guide the string saw along irregularly shaped profile. This new approach will enhance current surgical techniques for osteochondral injuries and PTOA surgical treatments. This mechanism can be used for extracting hard tissue grafts of virtually any shape and size. A highly flexible string saw needs to be developed to operate in these confined areas and an optimized roughness of the string needs to be determined so that the grafts tissue doesn't deteriorate. This technology could enable precision hard tissue harvesting in various other surgical procedures. Future work will include development of a powered saw and integration with an orthopedic robot that removes damaged area and profiles autograft.

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