



Midterm Safety of Carbon Dioxide Insufflation of the Knee During Arthroscopic Cartilage-Based Procedures

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Background: When compared with fluid arthroscopy, carbon dioxide (CO₂) insufflation offers an increased scope of view and a more natural-appearing joint cavity, and it eliminates floating debris that may obscure the surgeon's view. Despite the advantages of CO₂ insufflation during knee arthroscopy and no reported cases of air emboli, the technique is not widely used because of concerns of hematogenous gas leakage and a lack of case series demonstrating safety.

Purpose/Hypothesis: To investigate the safety profile of CO₂ insufflation during arthroscopic osteochondral allograft transplantation of the knee and report the midterm clinical outcomes using this technique. We hypothesized that patients undergoing CO₂ insufflation of the knee joint would have minimal systemic complications, allowing arthroscopic cartilage work in a dry field.

Study Design: Case series; level of evidence, 4.

Methods: A retrospective chart review was performed of electronic medical records for patients who underwent arthroscopic osteochondral allograft transplantation of the knee with the use of CO₂ insufflation. Included were patients aged 18 to 65 years who underwent knee arthroscopy with CO₂ insufflation from January 1, 2015, to January 1, 2021, and who had a minimum follow-up of 24 months. All procedures were performed by a single, fellowship-trained and board-certified sports medicine surgeon. The patients' electronic medical records were reviewed in their entirety for relevant demographic and clinical outcomes.

Results: We evaluated 27 patients (14 women and 13 men) with a mean age of 38 and a mean follow-up of 39.2 months. CO₂ insufflation was used in 100% of cases during the placement of the osteochondral allograft. None of the patients sustained any systemic complications, including signs or symptoms of gas embolism or persistent subcutaneous emphysema.

Conclusion: The results of this case series suggest CO₂ insufflation during knee arthroscopy can be performed safely with minimal systemic complications and provide an alternative environment for treating osteochondral defects requiring a dry field in the knee.

Keywords: knee; arthroscopy; carbon dioxide insufflation; cartilage allograft

Knee arthroscopy is one of the most frequently performed orthopaedic procedures, with an estimated incidence of 1 million procedures being performed in the ambulatory setting annually in the United States.¹¹ During this procedure, the joint space must be distended using a gas or fluid medium for the surgeon to properly visualize and execute necessary surgical intervention. Medical-grade carbon dioxide (CO₂) has been used by general surgeons for insufflation of the abdomen with rapid resorption and no detrimental adverse effects.^{10,14} The use of CO₂ for knee arthroscopy has been in practice since the 1980s, with some surgeons indicating an advantage over a fluid medium with regard to an improved view due to elimination of floating debris and blood and a more natural appearance of the joint cavity.^{1,8,12,17} Options for dry cartilaginous work in the knee include the use of arthroscopy without fluid

(dry scope) or CO₂ for insufflation. The majority of the case series related to gas insufflation during arthroscopy are several years old, with incidences of air emboli occurring only when atmospheric air is used in place of CO₂.^{3,6} Despite the advantages of CO₂ insufflation during knee arthroscopy, and no reported cases of air emboli, the technique is not widely used because of concerns of hematogenous gas leakage.⁹

Treatment of small (<2 cm²) osteochondral defects may consist of microfracture with an adjunct allograft.¹² These allografts may consist of dehydrated micronized human hyaline articular cartilage, which is rehydrated with autologous conditioned plasma before application to the defect. Utilization of this graft requires the defect to be dry for proper incorporation of the graft into the defect.^{12,18} Employing a gas medium for joint distension such as CO₂ allows for the dry environment necessary for placement of this cartilage matrix into the osteochondral defect. While this is 1 specific procedural indication, this can be broadly applied to other surgical techniques using grafts or

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biomaterial that would benefit from a dry field without the mechanical effects of a saline solution.

The purpose of this study was to investigate the safety profile of CO₂ insufflation during arthroscopic osteochondral allograft transplantation of the knee and report the midterm clinical outcomes using this technique. The surgeon's preferred insufflation technique is described along with the surgical technique and postoperative plan of care. It was hypothesized that patients undergoing CO₂ insufflation of the knee joint would have minimal systemic complications related to the CO₂ insufflation.

METHODS

After receiving institutional review board approval, we retrospectively reviewed the electronic medical records for Current Procedural Terminology code 29867 (arthroscopy, knee, surgical; osteochondral allograft [eg, mosaicplasty]). The inclusion criteria for the study were patients aged 18 to 65 years who underwent a knee arthroscopy procedure with CO₂ insufflation from January 1, 2015, to January 1, 2021 and had a minimum of 2 years of follow-up. All procedures were performed by 1 author (J.L.P.), a fellowship-trained and board-certified sports medicine surgeon.

Of 39 patients, 12 were excluded for not meeting the follow-up criterion, leaving 27 patients enrolled. The electronic medical records for these patients were reviewed in their entirety for relevant demographic and clinical information.

Surgical Technique

Preoperative Preparation. All patients received a femoral nerve block prior to entering the operating room. Once in the operating room, each patient received general anesthesia. The patient was positioned supine on the operating table. A tourniquet was placed around the upper thigh, and the extremity was prepared and draped in standard fashion. Using an Esmarch bandage, the lower extremity was exsanguinated and the tourniquet inflated to 300 mm Hg.

Insufflation and Arthroscopy. Insufflation settings and arthroscopic implantation were based on the original technique described by Mirzayan et al.¹² A standard portal was placed on the anterolateral aspect of the knee followed by the creation of an anteromedial portal using direct visualization. Normal saline was initially used to distend the joint during the diagnostic arthroscopy. Furthermore, if any concomitant procedures were necessary, they were performed at this time



Figure 1. View of osteochondral defect in carbon dioxide environment after microfracture has been performed.

to allow the saline to decrease the incidence of thermal damage with drilling or shaving and aid in debris removal. A motorized shaver was used to debride the articular cartilage defect, with care taken to maintain stable perpendicular margins. After measuring the defect, microfracture of the defect was then performed using an extraction drill to ensure bleeding bone was achieved and proper bone bridges between each hole were maintained (Figure 1).¹³ After these portions of the procedure were completed, the knee was drained, and CO₂ was introduced with an insufflation pump at a pressure of 15 mm Hg at a flow rate of 2 L/min. Any signs of gas embolism including arrhythmias, electrocardiogram changes, blood pressure variations, and oxygen saturation were monitored throughout the surgery and the recovery period.

Treatment of Osteochondral Defect. The cartilage matrix was prepared with autologous conditioned plasma at a ratio of 1 mL/0.8 mL. The graft was inserted into the defect and packed smoothly using a Freer elevator (Figure 2). Fibrin glue was then applied to the graft, smoothed, and allowed to dry for at least 5 minutes (Figure 3). At this point, the surgeon was able to return to standard fluid arthroscopy to remove any remaining debris. The knee was drained for the final time, concluding the arthroscopy portion of the case.

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Ethical approval was provided by the institutional review board of Tulane University (reference No. 2020-1347).

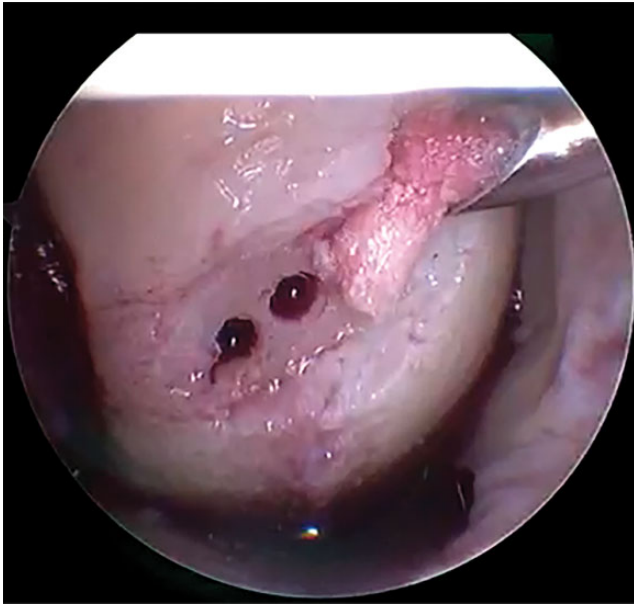


Figure 2. Osteochondral allograft being inserted into repair bed.

Postoperative Care

Patients were placed in a knee immobilizer and discharged home the same day if pain was adequately controlled. They were restricted to nonweightbearing for 6 weeks. Daily passive full range of motion was encouraged. At a minimum, patients undertook physical therapy 3 times a week for 8 weeks. Physical therapy consisted of manual therapy, edema management, gait and balance training, and functional exercises. However, protocols varied depending on injury severity, the presence of concomitant injuries, and the need for additional surgical interventions at the time of operation.

RESULTS

There were 14 female patients (51.9%) and 13 male patients (48.1%) with a mean age (\pm SD) of 38.0 ± 13.0 years (range, 20-65 years) and mean body mass index of 31.3 ± 7.6 (range, 20-52). The mean length of follow-up was 39.2 ± 8.8 months (range, 24.4-59.2 months).

Osteochondral defects were located on the patella in 12 patients (44.4%), medial femoral condyle in 7 patients (25.9%), trochlear groove in 3 patients (11.1%), tibial plateau in 2 patients (7.4%), and the lateral femoral condyle in 3 patients (11.1%). The average tourniquet time for all patients, regardless of procedure, was 88.0 ± 32.5 minutes (range, 20-140 minutes). For patients only receiving treatment for an osteochondral defect, the average tourniquet time was 53.3 ± 2.9 minutes (range, 50-55 minutes). Only 3 patients (11.1%) had isolated full-thickness osteochondral defects. Of the patients who had concomitant surgery, 14 patients (51.9%) had a lateral release, 12 patients (44.4%) underwent a medial patellofemoral ligament



Figure 3. Finished osteochondral allograft.

reconstruction, 12 patients (44.4%) had a tibial tubercle osteotomy, 11 patients (40.7%) had a meniscal repair or meniscectomy, 4 patients (14.8%) received a synovectomy, and 3 (11.1%) had an anterior cruciate ligament (ACL) reconstruction.

Of the total 27 patients, none sustained any systemic complications including signs or symptoms of gas embolism. In addition, there were no reported signs or symptoms of subcutaneous emphysema. There were 3 patients (11.1%) who had knee effusions that were aspirated by the physician. One patient (3.7%) sustained a subchondral fracture and subsequent collapse of the tibial plateau, resulting in a total knee arthroplasty at 24 weeks postoperatively. Tibial tubercle osteotomy hardware had to be removed at 25 weeks in 1 patient because of pain. Cellulitis around the incision occurred in 1 patient (3.7%) that resolved with oral antibiotics.

DISCUSSION

The most important finding demonstrated in the present study was that there were no adverse reactions or complications related to the CO₂ insufflation during arthroscopic treatment of the osteochondral defects.

Mirzayan et al¹² published a technique in which CO₂ insufflation is used throughout the entirety of the case when treating isolated osteochondral defects with microfracture and BioCartilage (Arthrex) adjunct. They also reported that by using this technique, the defect maintains a dry bed for placement of the graft, and in their experience, they found that alternating between CO₂ and fluid can leave fluid in the synovial tissues that can moisten the repair bed and compromise the adhesion of the allograft. However, osteochondral defects are commonly associated with additional injuries, with the present study reporting

79.3% of patients having additional injuries that required operative management.^{4,5} This involved mechanical work that potentially increased the risk of tissue injury due to the heat generated by the various arthroscopic instruments.¹⁵ The heat generated by this is minimized in a fluid medium, which is why the authors of the present study prefer to perform all concomitant procedures under fluid arthroscopy prior to switching to CO₂ insufflation for fixation of the osteochondral defect.

Similar to the present study, Vascellari et al¹⁸ used a sequence of fluid arthroscopy for the initial visualization of the injury as well as debridement and preparation of the repair bed. It should be noted they used matrix-induced autologous chondrocyte implant (Genzyme Biosurgery), which is seeded on collagen scaffolds and implanted in the defect and also requires a dry environment. Imbert et al⁹ compared the use of alternating low-pressure CO₂ insufflation with a fluid medium with fluid-only distension in arthroscopic ACL reconstruction. They reported a significant reduction in surgical time with the use of gas insufflation and attributed this to an enhanced view. They also reported a rate of minor subcutaneous emphysema of 6.2%, but argued that because of its spontaneous and quick regression, it may not be considered a complication.

Air embolism during or after CO₂ insufflation of the knee during an arthroscopic procedure has not been reported in the literature. However, there have been incidences of fatal air emboli reported by Habegger et al⁶ and Gruenwald³ in which atmospheric air was used in place of CO₂ for insufflation. It is important to note that CO₂ is nontoxic, readily absorbed by surrounding tissues, highly soluble in the blood, and exhaled through the lungs, whereas atmospheric air is not.^{14,17,19} Fatal and nonfatal air emboli have both been reported while using gas insufflation during shoulder arthroscopy procedures, but this has since been attributed to insufflation of a joint above the heart and the presence of noncollapsible veins exposed to the pressurized CO₂.^{2,7,16,20}

This study has limitations that need to be considered. First, given the study design, there was no control group of patients with whom to compare the present group. In addition, it was a retrospective case series with a limited number of patients. As this was a single-surgeon, single-institution study, outcomes are subject to that surgeon's technique and recommendations for the assigned surgical procedures. The complexity of the surgery varied between patients who had concomitant injuries and was not limited to isolated osteochondral defects. The presence of subcutaneous CO₂ was not monitored with radiography because of the risks of radiation but this could have demonstrated the presence of any residual nondissolved CO₂ in the acute postoperative period. There is also only an intermediate follow-up on the status of the cartilage and how it reacts to a drying environment with the presence of CO₂ gas. Studies are needed to fully evaluate the cartilage reaction on a cellular level, and long-term results should be monitored for potential adverse reactions. Ultimately, this study adds to the literature on the safety profile and midterm outcomes in patients undergoing CO₂ insufflation during arthroscopic procedures of the knee.

CONCLUSION

The results of this case series suggest CO₂ insufflation during knee arthroscopy is a safe and effective technique that provides an alternative environment for treating osteochondral defects of the knee with microfracture and matrix allografts. This technique can be generalized to be used for a variety of cartilage restoration procedures benefiting from a dry environment.

A Video Supplement for this article is available at <http://journals.sagepub.com/doi/suppl/10.1177/232596712111035454>.

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