The Effect of Radiofrequency Energy on Nonweight-Bearing Areas of Bone Following Shoulder and Knee Arthroscopy

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abstract

This prospective randomized clinical trial evaluated whether the use of radiofrequency energy devices (RFE) for soft-tissue ablation and coagulation cause thermal injury to bone. Fifty patients underwent one of three treatment modalities: electrocautery, monopolar RFE, or bipolar RFE. Preoperative and postoperative magnetic resonance imaging was compared to evaluate for evidence of osteonecrosis. Postoperative MRI of all patients did not reveal any osteonecrosis or subchondral edema. These findings indicate electrocautery, monopolar RFE, and bipolar RFE devices can be used safely for soft-tissue ablation and hemostasis.

In the 1990s, radiofrequency energy (RFE) in musculoskeletal applications made an immediate impact on the orthopedic community. Radiofrequency energy initially was used for soft-tissue ablation and shoulder joint capsular shrinkage.[1,2]

Although early results of clinical studies with thermal capsulorrhaphy were successful, a number of postoperative complications including recurrent instability, stiffness, capsular necrosis, axillary neuropathy, and articular cartilage injury have been reported. Because of safety issues and unpredictable results, the current use of thermal energy for shoulder capsulorrhaphy appears to be declining.[3-5]

Radiofrequency energy also has been used for the debridement of chondral injuries, particularly in the knee. The use of RFE has been reported to cause macroscopic smoothing and stiffening of chondromalacic articular surface, and RFE is considered an alternative to mechanical debridement and lavage for patients with symptomatic grade II or III chondromalacia.[6-17]

However, the use of RFE for chondral injuries can lead to extended chondrocyte death.[7] In addition, it has been shown bipolar RFE causes chondrocyte death of 2100 μg, which often extends to the subchondral bone, and is roughly three times greater than with monopolar RFE (737 μg).[7] Because of differential depths of penetration between monopolar and bipolar devices, it remains controversial which, if any of the devices, are safe for clinical applications.

Among the most common clinical uses of RFE are soft-tissue ablation and hemostasis when performing arthroscopic surgery, including subacromial decompression and anterior cruciate ligament (ACL) reconstruction. The advantage of RFE over more traditional methods, such as the mechanical shaver or standard electrocautery, is the ease of use, efficiency of soft-tissue ablation, and effectiveness for hemostasis, all of which lead to decreased operative time.

Currently, there has been no evidence to suggest the use of RFE for soft-tissue abla-

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Cover Story

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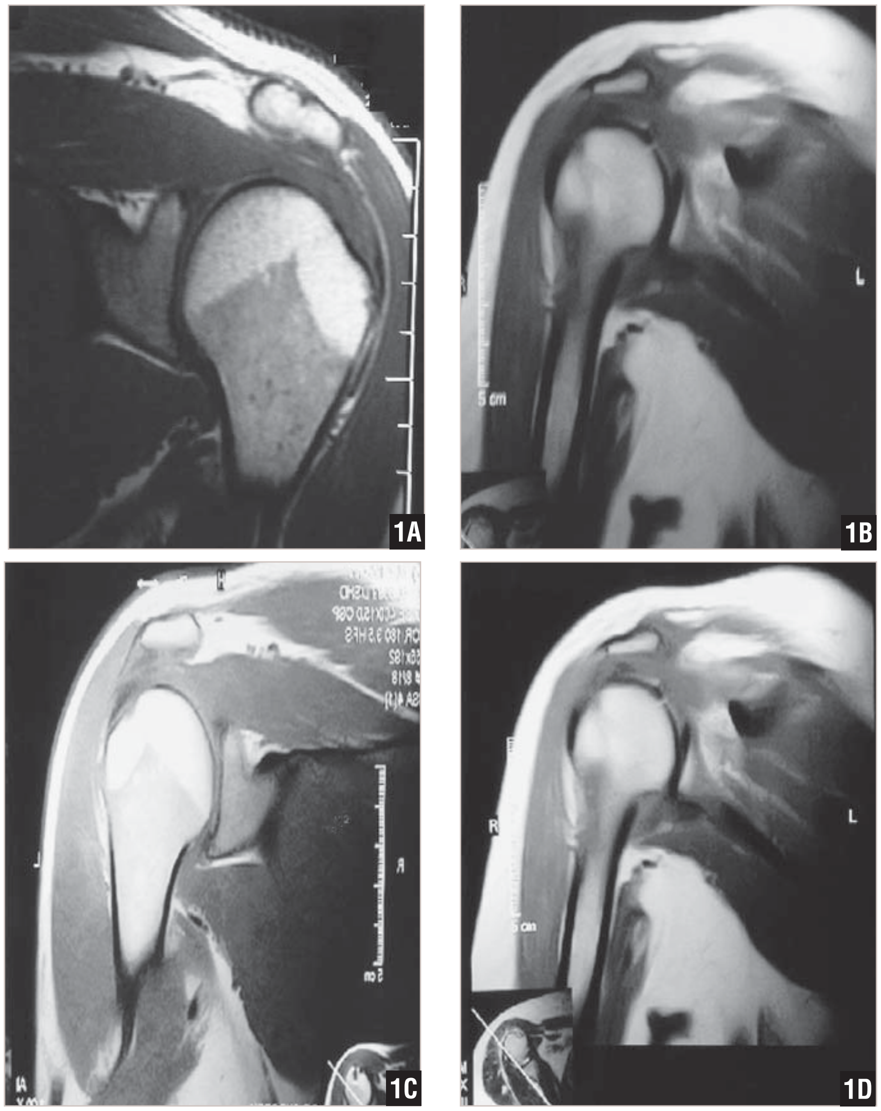

Figure 1: Representative preoperative coronal T1-weighted MRI of the shoulder (A). Representative postoperative MRIs from the electrocautery (B), monopolar RFE (C), and bipolar RFE (D) demonstrate no evidence of bony edema or osteonecrosis of the acromion.

tion and hemostasis causes adverse effects; however, there is growing concern that using RFE for soft-tissue ablation could result in thermal injury to bone or cartilage. Radiofrequency energy used in procedures such as arthroscopic subacromial decompression and notchplasty for ACL reconstruction may result in bone marrow edema and cellular death of the subchondral bone, which would override any benefit of these devices for increased convenience and decreased operative time.

This study evaluated the effect of electrocautery, monopolar RFE, and bipolar RFE on nonweight-bearing areas of bone by comparing pre- and postoperative magnetic resonance imaging (MRI). Magnetic resonance imaging has been shown to be the most sensitive radiographic study available to diagnose thermal injury to bone.[18]

MATERIALS AND METHODS

Patient Population

From June 2001 to June 2002, a total of 50 patients scheduled to undergo either arthroscopic subacromial decompression or ACL reconstruction were recruited for this study. All patients were older than age 18 years and had undergone preoperative MRI of the involved extremity. Patients who were undergoing revision surgery or who had contraindications for MRI were excluded. All patients enrolled in the study gave informed consent.

On the day of surgery, patients were randomly assigned to one of three treatment groups:

- group 1: Bovie electrocautery,
- group 2: monopolar RFE, and
- group 3: bipolar RFE.

The ratio of patients assigned to groups 1, 2, and 3 was 1:2:2, respectively. Four board-certified orthopedic surgeons who specialized in sports medicine or shoulder surgery performed all of the procedures.

Shoulder Arthroscopy

Patients undergoing shoulder arthroscopy were examined under anesthesia and placed in a beach chair position. Three standard arthroscopic portals were created, and the arthroscope was introduced into the glenohumeral joint.

The articular surface and surrounding structures including the glenoid labrum, the biceps tendon, and rotator cuff were evaluated. The arthroscope was placed in the posterior portal and directed toward the anterior portal entry site into the subacromial space. An additional lateral portal was placed below the level of the lateral acromion under direction visualization from the posterior portal.

Following thorough evaluation of the rotator cuff, a complete bursectomy was performed. This included removal of all soft tissue from the undersurface of the acromion in preparation for acromioplasty.

Monopolar RFE, bipolar RFE, or Bovie electrocautery was used for all soft-tissue debridement. When electrocautery alone was used, a mechanical shaver (Dyonics, Smith and Nephew, Andover, Mass) was used to remove soft tissue, and the electrocautery was used primarily for hemostasis.

The coracoacromial ligament was released and debrided back to a smooth and stable edge. A standard anteroinferior acromioplasty was performed using an arthroscopic barrel burr (Dyonics, Smith and Nephew) to remove the anteroinferior prominence of the acromion from the lateral portal and then using the burr from the posterior portal to create a type I acromion using a cutting block technique.

Soft-tissue and bony debris were irrigated out thoroughly. Additional procedures to address concomitant pathology, such as rotator cuff tears, also were performed. All additional procedures were performed arthroscopically.

ACL Reconstruction

For ACL reconstruction, patients were placed in a supine position and examined under anesthesia including Lachman, anterior and posterior drawer, varus and valgus, and pivot shift testing. The arthroscope was placed in the inferolateral parapatellar portal, and a standard diagnostic examination was performed confirming the presence of an ACL tear.

The residual ACL was excised with a combination of arthroscopic scissors and a mechanical shaver. Hemostasis was performed with the selected device.

While the graft was being prepared, the intercondylar notch was evaluated for notch configuration, tibial eminence, and notch osteophytes. The ligamentum mucosum and prepatellar fat pad was removed to permit enhanced visualization.

The selected device was used to ablate the soft tissue of the lateral wall of the notch and provide coagulation when required. Notchplasty was performed with a 1/4-inch curved osteotome and mallet, and a grasper was used to remove the osteochondral segment. The notchplasty was completed with a spherical arthroscopic burr until the over-the-top position was confirmed with an arthroscopic probe.

Any bleeding surfaces were coagulated with the selected RFE device. Additional procedures to address meniscal or articular pathology also were performed.

TABLE

Demographics of Subacromial Decompression and ACL Reconstruction Patients by Treatment Group

	Group 1 (Bovie) (*n*=11)	Group 2 (Monopolar RFE) (*n*=19)	Group 3 (Bipolar RFE) (*n*=20)
Subacromial decompression patients	5	9	11
Mean age (years)	45	46.6	53.6
ACL reconstruction patients	6	10	9
Mean age (years)	39	32.8	38.2
Mean time of postoperative MRI (weeks)	7.3	6.4	6.5

Abbreviations: ACL=anterior cruciate ligament, MRI=magnetic resonance imaging, and RFE=radiofrequency energy.

An arthroscopic Bovie device with a 90° L-hook tip (Dyonics, Smith and Nephew) was used with the Excalibur Plus PC (Conmed Corp, Utica, NY) at 40 W/40 W, bipolar RFE was performed with the Mitek VAPR with Side Effect (Mitek Worldwide, Westwood, Mass) at V2 mode (120 W/80 W), and monopolar RFE was performed with the Oratec Vulcan EAS with 90° Ablator-S (Oratec Interventions, Menlo Park, Calif) at 110 W/50 W. Devices were used according to the manufacturer's recommendations for tissue ablation and coagulation.

Postoperative MRI

Six to 8 weeks after surgery, patients underwent MRI. Postoperative MRI examinations were performed with an open MRI scanner (Arts II, Hitachi Corp). For subacromial decompression patients, oblique coronal and sagittal images with T1-weighted and FIR imaging techniques were obtained. For ACL reconstruction patients, axial, coronal, and sagittal images with T1-weighted and FIR imaging techniques were obtained.

Identical imaging was performed before and after surgery. All images were evaluated by a single, experienced radiologist who compared preoperative and postoperative images. Osteonecrosis or other bone injury was considered present if there was MRI evidence of subarticular bone marrow edema (signal hypointensity in T1-weighted images and signal hyperintensity in IR images), with or without MRI evidence of a reactive front or subarticular fracture line.

The radiologist was blinded to the treatment device. Any abnormal readings were immediately reported to the orthopedic surgeon and evaluated appropriately.

RESULTS

Patient Demographics

Of the 50 patients included in the study, 11 patients comprised group 1 (Bovie electrocautery), 19 patients comprised group 2 (monopolar RFE), and 20 patients comprised group 3 (bipolar RFE). Average age at surgery was 49.1 years (range: 40-65 years) for subacromial decompression patients and 36.2 years (range: 23-61 years) for ACL reconstruction patients. Patient demographics are summarized in the Table.

Of the 25 patients who underwent subacromial decompression, 18 had concurrent arthroscopic rotator cuff repair. There were also six cases of distal clavicle excision, six cases of intra-articular debridement, and four cases of biceps tenodesis.

Of the 25 patients who underwent ACL reconstruction, 13 received autograft tendons (7 bone-patellar tendon-bone grafts and 6 semitendinosus/gracilis grafts us-

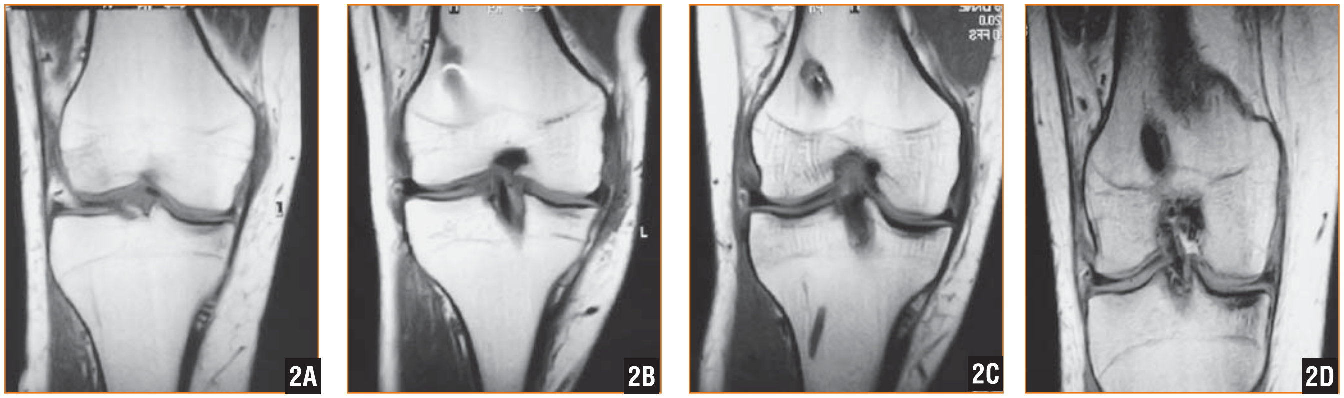

Figure 2: Representative preoperative coronal T1-weighted MRI of the knee (A). Representative postoperative MRIs from the electrocautery (B), monopolar RFE (C), and bipolar RFE (D) groups demonstrate no evidence of bony edema or osteonecrosis of the intercondylar notch.

ing a 4-strand technique) and 8 received bone-patellar tendon-bone allografts. Additionally, several concurrent procedures were performed including 10 cases of arthroscopic partial meniscectomy, 2 cases of arthroscopically assisted meniscus repair (1 repaired with inside-out and 1 repaired with the outside-in techniques), 2 cases of microfracture of the medial femoral condyle, 1 case of chondral debridement, and 1 case of loose-body removal.

Preoperative MRI

Preoperative and postoperative MRIs were compared for each patient. The preoperative MRIs revealed no subchondral bone abnormalities including evidence of avascular necrosis or bone marrow edema of the acromion in subacromial decompression patients or in the intercondylar notch in ACL patients.

Eighteen of 25 shoulder patients demonstrated full-thickness tears of the supraspinatus tendon at the insertion of the greater tuberosity of the humerus. Six patients had evidence of hypertrophic arthropathy of the acromioclavicular joint. Two patients had heterogeneous patches of signal intensity in the marrow of the proximal metadiaphysis of the humerus, with an appearance consistent with an enchondroma. One patient had large osteophytes of the articular margin of the humeral head.

All of the preoperative knee MRIs demonstrated a complete ACL tear with associated joint effusion. Ten patients had signal changes of the meniscus: 5 in the medial meniscus and 5 in the lateral meniscus. Eight patients demonstrated bone bruises of the posterior aspect of the lateral tibial plateau and above the sulcus terminalis of the lateral femoral condyle.

Three patients had medial compartment joint degeneration with articular cartilage erosion and osteophytes. Two patients had mild edema of the medial collateral ligament that was indicative of a sprain. One patient had extensive edema of the posterolateral aspect of the knee, particularly of the popliteus muscle. One patient had a nondisplaced fracture of the lateral tibial plateau with extensive edema, and another patient had a healed Segond fracture.

Postoperative MRI

Mean time to postoperative MRI was 6.8 weeks (range: 4.6-9.4 weeks). For the subacromial decompression patients, none of the preoperative MRIs demonstrated evidence of osteonecrosis of the acromion (Figure 1A), and no cases of bone marrow edema or osteonecrosis (Figures 1B-D) were evident on any of the postoperative MRIs. Similarly, for the ACL patients, neither the preoperative MRIs (Figure 2A) nor the postoperative MRIs (Figures 2B-D) revealed evidence of osteonecrosis.

Because no adverse events were noted on MRI, no differences were detected between the Bovie, monopolar RFE, and bipolar RFE groups. Of the shoulder patients, the radiologist reported a thinning of the anterolateral aspect of the acromion and an associated subacromial and subdeltoid effusion; additional findings consistent with the concurrent procedures were also observed.

The 18 patients with concurrent arthroscopic rotator cuff repair had magnetic susceptibility artifacts in the greater tuberosity resulting from the metallic anchors placed for the repair of the supraspinatus tendon with mild edema surrounding the anchors. The six patients with concomitant distal clavicle excision had a fluid space where the acromioclavicular joint was previously seen. The biceps tendon was no longer visualized in the four biceps tenodesis patients, and a nonmetallic fixation device in the metaphysis of the humerus also was described, consistent with arthroscopic biceps tenodesis.

The two patients with the heterogeneous patches of the humerus did not have any remarkable change in the character of these lesions on the postoperative MRI. One patient had a lesion in the proximal diaphysis of humerus suggestive of a stress fracture, and this patient returned to the clinic for further evaluation with no clinical correlation.

All of the ACL patients demonstrated a continuous, reconstructed ACL, mild bone marrow edema around the bone tunnels created for the ACL graft, and a small joint effusion. There were no cases of bone marrow edema or osteonecrosis of the intercondylar notch or other areas of the weight-bearing surface.

The 10 ACL patients who had concurrent partial meniscectomy demonstrated defects in the treated meniscus. Focal erosion of the articular cartilage down to the bone with high signal intensity of the subarticular marrow was evident in the two patients treated with microfracture of the medial femoral condyle.

DISCUSSION

Of all of the applications for RFE, soft-tissue ablation and coagulation have been the most widely adopted, primarily because of its efficiency and relative safety for these application. Electrocautery is an important device used in many arthroscopic procedures to control hemostasis, but the RFE devices have the added advantage of providing efficient soft-tissue ablation.

Among the two different types of RFE devices, many orthopedic surgeons prefer the bipolar RFE device because of its more rapid action. However, fears of greater cellular death may limit the use of bipolar RFE.

The results of this study demonstrated no evidence of bone necrosis or edema on postoperative MRI following the use of electrocautery, monopolar RFE, or bipolar RFE for ablation and coagulation for acromioplasty during subacromial decompression or notchplasty for ACL reconstruction, two common applications for these devices. In addition, at the time of postoperative MRI, no patients complained of severe pain localized to the acromion or distal femur that would provide clinical suspicion of thermal necrosis.

There are several reasons RFE for soft-tissue ablation on nonweight-bearing areas appears to be both effective and safe for arthroscopic procedures. In contrast to other applications, RFE for ablation removes or vaporizes the soft tissue from the area of interest with less concern for treatment time and precise temperature control.

Thermal capsulorrhaphy requires a temperature ranging between 65° and 75°C to heat-sensitive bonds, leading to unwinding of the collagen triple helix to a random coil and contracted state.[1] Lower temperatures are insufficient, and greater temperatures, particularly for a prolonged period of time, can be severely detrimental. Only a specific amount of tissue shrinkage can occur before RFE causes destruction of the material properties of the joint capsule.[19] The lack of a well-described endpoint for capsular shrinkage and an extremely narrow therapeutic range may contribute to the failures associated with thermal capsulorrhaphy.[5,20]

Thermal chondroplasty is believed to be able to debride chondral fibrillations and fissures to stabilize the articular surface, thereby reducing the inflammation and ultimately the progression of chondromalacia.[7] Kaplan et al[8] and Turner et al[17] performed studies with bipolar RFE on articular cartilage with histologic analysis; both reported minimal chondrocyte death and concluded bipolar RFE was safe for thermal chondroplasty.

In contrast, Lu et al[10] performed studies using confocal laser microscopy to detect cell viability. They found both monopolar and bipolar RFE cause chondrocyte death that may not be detected by more traditional hematoxylin-eosin with safranin O staining.

Shellock and Shields21 evaluated the articular surface temperatures of bipolar RFE using fluoroptic thermometry. They reported a temperature range of 54°C to 78.5°C in a 2-second time interval and therefore concluded Mitek VAPR bipolar RFE was safe at the V2:40 setting.

Edwards et al[22] also studied the temperature of RFE devices at three different depths of cartilage matrix. They found significant differences between bipolar and monopolar RFE depths of thermal heating, and the bipolar RFE device resulted in matrix temperatures (>70°C) high enough to cause chondrocyte death as deep as 2000 μm beneath the chondral surface. In addition to causing cell death to adjacent healthy chondrocytes, cell death continued to occur even after the initial delivery of RFE when used on articular cartilage.[14]

In a recent case report, an 8-mm, grade 3 chondromalacia defect of the medial femoral condyle was treated with bipolar RFE that effectively smoothed the surface.[23] Second-look arthroscopy at 11 months revealed a defect with stable edges but a markedly recessed central region, suggesting progressive cartilage loss.[23]

Edwards et al[7] demonstrated bipolar RFE causes three times more chondrocyte death than monopolar RFE. Thus, there is a greater chance death may extend to the level of the subchondral bone, suggesting the potential for osteonecrosis.

Ongoing studies in thermal chondroplasty are attempting to characterize the optimal treatment time and lavage solution temperature.[12,13] A fundamental difference between the use of RFE for capsular shrinkage or chondroplasty and its use for ablation is that thermal capsulorrhaphy and chondroplasty aim to alter tissue properties without inherent tissue destruction.

Because of the extremely narrow therapeutic range, improper implementation of RFE can lead to harmful consequences. Alternatively, the goal of RFE ablation is to ablate the soft tissue itself without affecting the surrounding structures.

The lack of bone necrosis found in this study following tissue ablation may be explained by biologic or biomechanical differences between weight-bearing and nonweight-bearing areas of subchondral bone. Studies have been conducted to characterize the vasculature of the lateral and medial femoral condyles.[24,25] It is possible relative differences in vascularity between these locations may provide relative protection to the acromion or intercondylar notch region.

Another fundamental difference between areas of weight-bearing and nonweight-bearing subchondral bone may be purely mechanical. Soon after the intro-

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duction of lasers, cases of iatrogenically induced osteonecrosis were reported following arthroscopic laser meniscectomy and thermal chondroplasty.[26-28]

Similarly, basic science studies with RFE suggested thermal injury might cause full-thickness chondrocyte death to the level of the subchondral bone.[7,11] The pathogenesis of osteonecrosis involves the creeping substitution of cortical bone and rapid osteoblast repair of cancellous bone.[29] During this process, necrotic bone is being replaced with repair tissue, and the structurally compromised bone is unable to withstand typical mechanical loads.[29] Weight-bearing areas therefore are more prone to subchondral fractures and subsequent collapse.

Thermal injury also may produce cellular necrosis of nonweight-bearing subchondral bone, but the lack of a significant mechanical load may permit an adequate repair and cellular repopulation. The mechanical strength of necrotic bone is not believed to be affected, so it is plausible that nonweight-bearing areas are able to maintain their structural integrity because they are not exposed to excessive loads. Further studies are necessary to determine whether nonweight-bearing areas of subchondral bone undergo subclinical necrosis or necrosis with repair.

There are several strengths to this study. Patients were evaluated prospectively and randomly assigned to treatment groups. Surgery was performed by board-certified orthopedic surgeons who specialized in sports medicine or shoulder surgery. Preoperative and postoperative MRIs were compared by a musculoskeletal radiologist blinded to the treatment groups.

There also are several potential limitations to this study. Magnetic resonance imaging was selected in this study to evaluate the safety of RFE because MRI has been shown to be the most sensitive study available to diagnose osteonecrosis.[18,30] In addition, 6 weeks postoperative was selected as the time for MRI because this should be an adequate period of time for any bone edema to be detected, yet not too long after surgery for any short-term effect to be recognized. However, it is possible a delayed effect could be seen following the use of these devices that would not be detected until later in the postoperative period.

In addition, the use of the burr to remove bone from the intercondylar notch and underside of the acromion is another potential limitation of the study. It is possible any effect of the thermal devices on the bone is not seen because these areas of bone are removed with a burr during the remainder of the procedure, namely acromioplasty or notchplasty.

However, the devices were used in the usual manner for ablation during acromioplasty or notchplasty. Therefore, by MRI criteria, there was no extension of thermal injury beyond the usual area of acromioplasty or notchplasty. Thus, using these devices for the purpose of ablation during these two procedures does not appear to lead to significant thermal injury to the remaining bone.

Another potential limitation is the use of multiple surgeons for the study. Although the procedures were all performed in a similar fashion, there is the potential for variable use with the devices. This would include the duration and frequency of their use, both of which have implications for their safety. However, the use of four surgeons, as opposed to a single surgeon, increases the generalizability of the results to other arthroscopic surgeons.

Finally, this study is limited by the small sample size. It is possible an effect on subchondral bone is present in a subset of patients that was not detected by the small sample. Given the large number of arthroscopic subacromial decompression and ACL reconstructions performed annually, this rare effect could have a large clinical application, if present. This effect could only be determined by further study in a larger group of patients.

CONCLUSION

There was no radiographic evidence to suggest osteonecrosis 6 to 8 weeks postoperatively following the use of monopolar RFE, bipolar RFE, or electrocautery for soft-tissue ablation and hemostasis during subacromial decompression or intercondylar notchplasty during ACL reconstruction. These devices appear to be safe and effective for these procedures. However, additional studies with a larger sample size and clinical follow-up are necessary to confirm these conclusions.

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