The Effects of Radiofrequency Bipolar Thermal Energy on Human Meniscal Tissue

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Abstract

This study performed the first in vitro histological analysis of the effects of bipolar thermal energy on human meniscal tissue. Sixteen fresh human menisci were mounted on a cutting block and placed in a water bath simulating an arthroscopic environment. Each specimen was divided into four sections and randomized to one of four treatment options: 1. thermal ablation with a bipolar multielectrode 3 mm Covac wand (power setting 3); 2. thermal ablation with a bipolar multielectrode 3 mm Covac wand (power setting 7); 3. resection with a scalpel blade; and 4. resection with a motorized 4.5 full-radius resector. Six micron sections were cut and stained with Hematoxylin and Eosin and Masson’s trichrome stain. Menisci were evaluated for the contour of the cut edge: straight, jagged, frayed, or combined. The zone of thermal necrosis and zone of thermal alteration were determined by examining the differential staining of the connective tissue and measuring the affected area.

Menisci treated with the bipolar thermal probe were noted to have a smoother contoured edge in comparison to motorized cutters. The zone of thermal penetration for the Arthrocare power setting 3 averaged 0.18 mm (range: 0.09 to 0.20; SD 0.04) and for Arthrocare power setting 7 averaged 0.33 mm (range: 0.26 to 0.36; SD 0.03). The difference in thermal penetration between Arthrocare power settings 3 and 7 was 0.15 mm. This was statistically significant at p < 0.0001 (95% CI: 0.11 to 0.19 mm). The zone of thermal penetration was non-existent for the shaver and scalpel groups. This study provides the first histological description of the effects of bipolar radiofrequency energy on meniscal tissue. It demonstrates that there is intrasubstance thermal penetration and alteration of the meniscal tissue. Its clinical significance is unclear and further in vivo studies are needed to address its clinical applicability.

The recent resurgence of electrosurgery for arthroscopic partial meniscectomies has been fueled by the development of bipolar electrodes (i.e., Covac™ wand, Arthrocare, Sunnyvale, CA; VAPR™ Flexible Side Effect Electrode, Mitek Surgical Products, Inc, Westwood, MA). Prior to the advent of these probes, the unipolar configuration, consisting of a small treatment electrode and a large grounding pad attached to the patient’s leg, was the type conventionally used in arthroscopy. The current passed through the patient’s body from the electrode to the grounding pad, which was often a significant distance away. This resulted in current scattering, decreased current, and an increased demand for energy resulting in penetration of the meniscus and surrounding tissue. The bipolar configuration has both electrodes (treatment electrode and ground pad) in the probe tip. The current passes through the tissue and back to the probe tip without passing through the rest of the patient. Theoretically, this increases the current density at the treatment site allowing increased cutting efficiency, decreased damage to other local tissue, and decreased thermal penetration. The ablation is achieved as charged particles in the conducting fluid (0.9% normal saline) are accelerated toward the meniscus secondary to the voltage gradient created between the conductive media and the tissue. These charged particles are able to cause the dissociation of the molecular bonds within meniscal tissue resulting in volumetric removal. Due to the short range of these accelerated particles, the dissociative process is theoretically confined to the surface layer of the target,
with minimal to no thermal penetration. These claims of minimal penetration have recently been challenged with reports of significant thermal penetration in articular cartilage. However, the literature is lacking reports on the effects of bipolar thermal energy on meniscal tissue. The purpose of this study was to perform the first in vitro histological analysis describing the effects of bipolar thermal energy on meniscal tissue.

Materials and Methods
Sixteen fresh human menisci were harvested from patients undergoing total knee arthroplasty and stored in normal saline at room temperature. Patients ranged in age from 57 to 81 years with a mean age of 63. All testing was performed within 1 hour of harvest. Menisci were mounted on a 5x5 cm cutting block and placed in a water bath simulating an arthroscopic environment with an in flow pump creating a constant flow of normal saline at room temperature over the sample. Each specimen was divided into four sections. These sections were then randomized to one of four treatment options:

1. Thermal ablation with a bipolar multielectrode 3 mm Covac wand (Power setting 3) (Arthrocare, Sunnyvale, CA);
2. Thermal ablation with a bipolar multielectrode 3 mm Covac wand (Power setting 7);
3. Resection with a scalpel blade; and
4. Resection with a motorized 4.5 full-radius resector.

(Dyonics, Smith and Nephew, Memphis, TN).

Sections of meniscus – anterior, posterior, and middle – were randomly assigned the treatment options to assure an even distribution of treatments for each meniscal section. A uniform distribution of anterior and posterior meniscal specimens from the medial and/or lateral meniscus was confirmed for each treatment group. A 1 cm wide by 0.5 cm deep section of meniscal tissue was removed using each of the described techniques. A gentle sweeping motion was used with the thermal probe to avoid excess heat being generated at one location of the meniscus. Our goal was to reproduce what occurs clinically when partial meniscectomy is performed using thermal probes and to follow the guidelines of the manufacturer. The remaining specimen was then prepared for histological analysis (Fig. 1). Histological preparation included fixation in 10% formaldehyde in a phosphate buffer (pH 7.4). Samples were dehydrated in graded series of alcohol and embedded in paraffin. Six micron sections were cut and stained with Hematoxylin and Eosin (H&E) and Masson’s Trichrome. Histological analysis was performed by an experienced musculoskeletal pathologist. Menisci were evaluated grossly and microscopically for the contour of the cut edge: straight, jagged, or combined. A straight cut was defined as the lack of peaks and valleys of meniscal tissue seen both grossly and microscopically while jagged was defined as presence of peaks and valleys of meniscal tissue seen both grossly and microscopically. The person evaluating the meniscal specimens was not blinded.

Figure 1 Meniscal specimen demonstrating the four treatment areas with section A treated with the bipolar thermal probe and cross section taken for histological analysis.

Figure 2 Masson’s trichrome stain of meniscal specimen resected with Arthrocare power setting 3 demonstrating altered staining at meniscal surface indicating thermal penetration (20X).
to gross evaluation (surgeon) or microscopic evaluation (surgeon and pathologist).

The zone of thermal necrosis and zone of thermal alteration were determined by examining the differential staining of the connective tissue and measuring the affected area. The zone of thermal necrosis was defined as that area of meniscus with cellular death and lack of extracellular matrix. The zone of thermal alteration was defined as that area of meniscus with abnormal staining pattern, as compared to the scalpel control group, with only mild alteration of the extracellular matrix. A minimum of three measurements of the depth of thermal alteration were made for each treatment modality in each specimen and results were averaged.

Results

Grossly, a general pattern was observed. The scalpel produced the smoothest cut, followed by the thermal probe. The shaver produced the roughest cut of all treatment modalities. This was confirmed histologically. The shaver had a jagged surface, and the thermal probe specimens had a mildly jagged surface combined with areas that were relatively smooth.

The zone of thermal necrosis on every specimen was represented by a thin black line, defined as that area of meniscus with cellular death and lack of extracellular matrix. This was too small to measure accurately with the microscope used in this study. However, as can be seen from the photographs, the black line is considerably smaller in comparison to the depth of thermal penetration. The zone of thermal penetration was non-existent in the shaver and scalpel group. The zone of thermal penetration for the Arthrocare power setting 3 averaged 0.18 mm (range: 0.09 to 0.20; SD 0.04) (Fig. 2) and for Arthrocare power setting 7 averaged 0.33 mm (range: 0.26 to 0.36; SD 0.03) (Fig. 3). This equated to a mean difference of 0.15 mm between the two settings. These results were statistically significant at $p < 0.0001$ (95% CI: 0.11 to 0.18 mm).

Discussion

Artiomi and Yamamoto in 1972 were the first to report on the uses of electrothermal energy in arthroscopy where they described its use for knee synovectomy. The present study is the first, to our knowledge, describing the in vitro effects of bipolar thermal energy on human meniscal tissue. Previous studies have focused on the results of unipolar radiofrequency energy for partial meniscectomy. In 1986, Schosheim and Caspari performed an in vivo study looking at effects of a 40 W probe on rabbit menisces. Histologically, there was a necrotic zone followed by a hypocellular zone. The necrotic zone decreased in depth from a range of 0.05 to 0.15 mm on the 2-week menisci to a range of 0.02 to 0.05 on the 4-week specimens. By 6 months, the necrotic zone had disappeared and there was no apparent difference between the experimental and control menisci.

Balduini and colleagues used a unipolar electrosurgical device with power outputs ranging from 40 W to 60 W. Average depth of meniscal necrosis was 0.12 mm. Miller and associates reviewed the results in 58 patients who underwent partial meniscectomy using a thermal probe set at either 375 W or 175 W output. The average depth of thermal penetration was 0.29 mm. In 27 of the 58 specimens, no evidence of thermal damage could be found. Two patients underwent repeat arthroscopy and meniscal biopsy at 7 and 21 months postoperatively and revealed tissue indistinguishable from normal menisci at the surgical site. In 1992, Bert took acute biopsies from menisci of human subjects after being treated with a “loop probe” at 50 to 60 W. Thermal damage extended an average of 0.35 mm. Twenty-one patients required repeat arthroscopy and had meniscal specimens taken at times ranging from 6 months to 4 years postoperatively. None of the specimens showed any evidence of residual damage when analyzed microscopically under H&E and Masson’s trichrome stain. Recently, in 1995, Vangsness and coworkers conducted an in vitro study on human meniscal tissue with a unipolar electrothermal energy probe with a power output of 60 W. This produced an average depth of tissue necrosis of 0.02 mm and thermal change to an average depth of 0.26 mm. Sherk and col-

**Figure 3** Masson’s trichrome stain of meniscal specimen resected with Arthrocare power setting 7 demonstrating a larger area of altered staining at the meniscal surface indicating thermal penetration. This jagged surface was seen with meniscal ablation at higher power settings similar to traditional unipolar devices (30X).
leagues\(^9\) demonstrated thermal penetration ranging from 0.047 mm to as high as 0.478 mm. The results from the present study for the lower Arthrocare setting 3 (recommended by manufacturer) compare favorably with the results from unipolar studies with no evidence of thermal necrosis and lower levels of thermal penetration, averaging 0.29 mm.\(^{12}\)

While the literature supports that the meniscus acutely sustains thermal damage with the use of unipolar thermal electrodes, it appears to heal to normal tissue by 6 to 7 months.\(^{10-13}\) However, it is unclear whether during the healing process the meniscus is more susceptible to injury. The goal should be to limit the amount of thermal damage to allow decreased susceptibility to further injury and decreased healing time. Bipolar thermal probes create higher current densities at lower power outputs than do unipolar devices. This was confirmed by Baggish and Tucker\(^{14}\) who showed in rabbit uterus that, at given power outputs, a bipolar configuration produced less thermal damage than a unipolar configuration with comparable cutting and coagulation ability. In addition, current flow is better controlled with bipolar probes, avoiding current flowing through the patient to the ground pad resulting in thermal dispersion and possible damage to articular cartilage while meniscectomy is performed. The results of the present study prove only that despite these theoretical benefits, thermal energy does penetrate the meniscus, as high as 0.36 mm with the Arthrocare bipolar Covac thermal probe at setting 7. Without direct comparison with a unipolar probe, it is difficult to draw conclusions about the amount of penetration and whether bipolar probes cause less thermal penetration than unipolar probes. Nonetheless, it does show that there is thermal penetration acutely. However, it is unclear whether this will be meaningful clinically or whether it will resolve at follow-up.

Limitations of this study were that it was in vitro and performed on degenerative meniscus taken from osteoarthritic knees that may respond differently to thermal heating. However, the control specimens (scalpel group) displayed no abnormal staining or collagen degeneration at the cut meniscal surface. Our study also lacked a standardized method of passing the thermal probe over tissue as has been reported by Lu and associates\(^7;\) they reported on a motorized jig able to control speed and force applied by the thermal probe. Our desire was to reproduce what is occurring clinically. However, this unfortunately introduces human error, which may have affected results.

**Conclusion**

The use of bipolar radiofrequency thermal probes for partial meniscectomy in this study was associated with thermal penetration of the meniscus. In addition, there was a significant difference in depth of thermal penetration between specimens resected with Arthrocare wand at setting 3 and those resected with the device at setting 7. However, further in vivo and clinical studies need to be performed to determine the ultimate significance of this penetration.

**References**