The use of tissue temperature control for monopolar thermal chondroplasty
Historical Perspective

The surgical treatment of articular cartilage lesions presents a great challenge to clinical orthopedics. The pattern and presentation of these chondral abnormalities can vary greatly, ranging from isolated and acute problems to chronic lesions extending into the degenerative joint. Fortunately, symptoms associated with articular lesions are not always severe and can often be managed conservatively.

Arthroscopy is a treatment option for chondral lesions that fall in the middle of this clinical management paradigm: that is, chondral lesions that are not going to be restored and are not so severe that they require prosthetic arthroplasty. Mechanical shaving or drilling of articular lesions has been employed for many years, but the long-term results have not been what many consider optimal. The availability of thermal treatment may enable the surgeon to obtain a smoother joint surface than with mechanical devices while maintaining as much healthy cartilage as possible.

This technique describes monopolar thermal chondroplasty using the Smith & Nephew TAC®-C II Probe. This probe is designed for minimal depth penetration while providing a smooth articular surface after treatment.
Planning Thermal Surgery

Current recommendations are to treat only those areas with more than 1.5 mm of cartilage thickness. In areas of thinner tissue, care should be exercised to eliminate the possibility of thermal effects reaching subchondral bone. Before surgery, X-rays and/or MRI may be used to estimate cartilage thickness in the areas to be treated, with the understanding that some depth of the cartilage will be thermally denatured.

**Indications for thermal chondroplasty:**

- Patellar, femoral, and/or tibial lesions

  Grade II lesions—see Figure 1
  (Outerbridge Classification)

  Grade III lesions—see Figure 2
  (Outerbridge Classification)

**Contraindications for thermal chondroplasty:**

- Grade IV lesions

  Osteochondral grafts and/or autologous chondrocyte transfer sites

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Outerbridge Classification - IKDC

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<tr>
<th>Grade</th>
<th>Description</th>
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<tr>
<td>I</td>
<td>Softening/swelling of cartilage surface</td>
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<tr>
<td>II</td>
<td>Fissuring and delamination of surface may extend to approximately half the cartilage surface</td>
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<tr>
<td>III</td>
<td>Extended fissuring down to subchondral bone; crabmeat-like appearance, but subchondral bone is not exposed</td>
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<td>IV</td>
<td>Exposure of subchondral bone</td>
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Figure 1. Grade II lesion

Figure 2. Grade III lesion
Surgical Technique

Step 1
Before applying thermal energy, the surgeon debrides the lesion with a nonaggressive mechanical shaver such as the Smith & Nephew Dyonics® TurboWhisker® Disposable Blade (Figure 3) for a preoperative view. The objective is to perform careful mechanical debridement, resecting the degenerative tissue back to a stable margin.

Note: Use of ablation devices for cartilage debridement is strongly discouraged as they can cause excessive thermal damage.

Step 2
Once the lesion has been grossly debulked (Figure 4), the surgeon reduces pump pressure and seals any leaking cannulas. This minimizes the cooling effect of the irrigation fluid by creating a static fluid environment – minimal to no fluid flow is desired.

Note: Reducing or stopping fluid flow provides the best tissue effect at the lowest possible power setting.4

Step 3
Using standard arthroscopy portals, the surgeon introduces the Smith & Nephew TAC™-C II Probe into the joint (Figure 5).

Note: Power and temperature values are automatically set at 15 watts and 70°C. These values, established through multiple scientific studies, optimize the thermal effect with minimal depth of penetration.3, 5, 6

During treatment the TAC-C II probe relays tissue temperature readings 50 times per second to the Smith & Nephew Vulcan® Generator, which makes automatic adjustments to maintain the selected treatment temperature.
Step 4

With the probe tip in contact with the target lesion, the surgeon activates RF delivery and begins a slow, continuous movement across the lesion. Smoothing and contraction of the fibrillated cartilage surface should be visible during treatment. One or two passes in a paintbrush technique will adequately smooth the fibrillated cartilage surface. The surgeon should be able to feel the change in tissue density once it is thermally fused.

Note: For optimal thermal effect the probe tip should be in full contact with the target tissue (Figure 6). Partial or angled contact may reduce the desired tissue effect and should be avoided. Optimal temperature sensing and control occurs when the probe tip is in full contact with the tissue.

Step 5

After the surface has been smoothed (Figure 7), the surgeon is ready to move the probe to the next treatment area.

Note: Multiple treatments (three or more passes or prolonged contact) of the same area should be avoided.
Technical Tips and Suggestions

See Figures 8 and 9 for a representative example of a pre- and post-thermal treatment.

Keep the probe tip in full contact with the tissue and maintain gentle pressure during treatment.

Reduce pump pressure and seal any leaking cannulas to minimize fluid flow through the joint.

Bend the malleable Smith & Nephew TAC™-C II Probe shaft with the Smith & Nephew Probe Bender to better access hard-to-reach lesions. Use only the Smith & Nephew Probe Bender to bend the probe.

Maintain probe movement during RF delivery.

Postoperative Guidelines

The postoperative regimen following thermal chondroplasty is identical to that of mechanical debridement. As in all arthroscopic treatments, it may take three to six months for patients to experience maximum physical improvement from the surgery. Efforts to control postoperative effusion and swelling — such as NSAIDS, cryotherapy, and compressive sleeves — may be used. Additionally, patients should be strongly advised as to the importance of physical rehabilitation and conditioning for maximum recovery. Well toned and conditioned muscles of the lower extremity can effectively relieve stress on the degenerative joint. Regular aerobic exercise for the degenerative joint can also help maintain motion and muscle tone after arthroscopic surgery.
Advanced Principles of Tissue Temperature Control

Monopolar Thermal Chondroplasty—A Smoother Joint Surface

Use of mechanical shavers to debride chondral lesions has been shown to provide a positive clinical effect.\(^1\),\(^2\) Unfortunately, these results can be quite variable and over time tend to decline. One reason may be that even the best mechanical debridement leaves a rough, fibrillated joint surface (Figure 10). Further, mechanical debridement or abrasion has been shown to create 100 to 200 microns of chondrocyte death.\(^3\) This may be due to the shearing forces (mechanical injury) of a rotating cutter/blade and the associated disruption of the intracellular matrix. Shavers by nature are aggressive in their ability to remove tissue and it is an ongoing challenge to control the depth of tissue removal. Tissue density, blade style, speed, and tip pressure are all crucial factors in mechanical debridement.

With new thermal techniques surgeons may now achieve a unique tissue effect that is superior to mechanical debridement. Multiple scientific studies have shown that collagen has a unique reaction to thermal energy.\(^9\),\(^10\),\(^11\) When heated, the triple-helix collagen fibrils present in ligaments and cartilage contract. At temperatures above 65° C, contraction and fusion of the collagen can occur. The fusion effect of thermal treatment creates a surface much smoother (Figure 11) than what can be achieved with mechanical instruments alone.\(^3\)

Monopolar RF Tissue Interaction—Tissue Impedance Impacts Thermal Effect

Different tissue types have different electrical resistance (impedance), a phenomenon well exemplified by ligamentous tissue and articular cartilage (Figures 12 and 13). The high impedance of articular cartilage (400–500 \(\Omega\)) and the underlying bone (900–1100 \(\Omega\))\(^11\), for example, discourages the conduction of RF energy into this type of tissue. During treatment, RF energy will flow away from the cartilage to the surrounding low impedance saline, creating a superficial thermal effect. Ligamentous tissue, on the other hand, provides a better RF energy pathway due to its lower impedance; and RF treatment creates a deeper heating effect.\(^11\)
Tissue Temperature Control for Monopolar Thermal Chondroplasty

Cartilage Chemistry, Enzymes, and the Degenerative Knee

The degenerative knee patient often has a painful synovitis and reactive effusion (Figure 14). Those with moderate pain usually have minimal synovitis without effusion. For the patient with painful synovitis, the pathobiology of their condition is reasonably well understood. An enzyme soup (effusion) results from the synovial irritation that comes from the articular cartilage matrix degeneration. The shedding of cartilage debris as the joint degenerates causes an inflammatory response by the synovium eliciting a joint effusion. Clinical symptoms of warmth, swelling and pain are a result of this degenerative joint pattern.

The Benefit of Tissue Temperature Control

Chondrocytes are highly sensitive to temperature with limited ability to repair themselves. Any thermal method used to smooth articular lesions must have automated power and temperature control to ensure consistent, reproducible tissue effects. Variables such as treatment speed, power output, irrigation fluid temperature, and tip contact pressure, can affect tissue heating and the depth of thermal injury (Figure 15). There is a direct relationship between treatment temperature and depth of thermal effect: the higher the treatment temperature, the deeper the thermal effect.

Figure 14. Enzymatic cascade effect

Figure 15. Comparison of cartilage matrix temperatures of depths of 0.5 mm and 2.0 mm without irrigation flow

Thermometric measurements of cartilage matrix temperatures demonstrate that treatment with monopolar temperature control provides significantly lower tissue temperatures compared to bipolar ablation probes. The above data compares cartilage matrix temperatures at depths of 0.5 mm and 2.0 mm.

For more complete information on Cartilage Matrix Temperatures, please review Arthroscopy, Vol. 18, No. 4, April 2002:339-346. Additional studies have confirmed that monopolar temperature control consistently results in less chondrocyte death than bipolar ablation devices.
Advanced Temperature Control

The Smith & Nephew Vulcan™ Generator utilizes an advanced computer-controlled algorithm that automatically adjusts output power to maintain the selected treatment temperature. Power adjustments occur as rapidly as 50 times per second for optimal control and consistent tissue effects from one patient to the next.

Coupled with the TAC™ probe, significant reductions in the depth of thermal injury have been documented (Figure 16). Bipolar non-temperature controlled devices (ablation probes) have been shown to penetrate 70–90% deeper than temperature-controlled monopolar probes.

Enhanced Tissue Effect

By thermally smoothing fibrillated or degenerative cartilage, thermal chondroplasty may be able to retard the degenerative process of cartilage delamination and fretting. It is not a reparative or stimulatory effort, but focuses on sealing and smoothing the surface of the lesion. The goal is to retard the continued breakdown of cartilage and minimize the chemical by-products and enzymes that are closely tied to synovitis, effusions, and pain.

The use of monopolar RF energy to smooth and seal fibrillated chondromalacia lesions has been studied in a number of animal and human tissue models. Further clinical and scientific research is needed to more precisely quantify this tissue effect and establish clinical validity relative to mechanical debridement.

Assessment of RF/Thermal Energy Effect on Tissue

Confocal Laser Microscopy

Confocal Laser Microscopy (CLM) uses a dual-stain approach to assess cell viability. This staining technique has been used on a number of tissue types and is currently used by the NIH and the FDA.

The first stain is called calcine. It is absorbed by living cells and processed in the protoplasm by esterase activity, causing the cell to fluoresce green when viewed under a confocal laser microscope. The cell must be alive and metabolically active to metabolize the calcine. Inactive or dead cells cannot create the chemical reaction needed to produce the green fluorescence seen in CLM.

Figure 16. Use of monopolar RF systems with a tissue temperature control system has been shown to dramatically reduce the depth of thermal injury. The operative goal is thermal fusion of the fibrillated cartilage surface while minimizing thermal injury to the underlying viable chondrocytes.
The second dye is ethidium homodimer-1 (EH-1). It penetrates the cell only if the cell membrane is damaged.\(^{13}\) The molecular size of EH-1 is approximately 100 times the size of molecules that normally move by osmosis through cell membranes (such as sodium or potassium chloride). Cell membranes that allow the large molecules of EH-1 to pass through are significantly damaged. Once through the membrane, the dye is attracted to the cell’s nuclear material, where it chemically binds and then fluoresces red under confocal laser microscopy. EH-1 is unable to penetrate metabolically active cells with intact cell membranes.

The use of these two dyes is an effective double-check of cell viability. In essence, “Red is Dead” and “Green is Alive” (Figure 17). Processing and staining of these samples is performed at 4° C, according to standard laboratory protocols, to preclude any possibility of cell wall/pore dilation due to specimen temperature variations.\(^{14}\)

**Hematoxylin and Eosin Staining**

Hematoxylin and eosin (H&E) staining viewed under light microscopy is considered the benchmark for assessing cell morphology in tissues such as cartilage; but not necessarily cell viability.\(^{6}\) Hematoxylin has an affinity for the nucleic acids of the cell nucleus. Eosin, an acidic dye, has an affinity for the cytoplasmic components of the cell.

The different chemical bonds created by these two dyes enable accurate viewing of cell orientation, location, and shape. Subtle changes in tissue type or morphology are more easily visualized. Figure 18 shows articular cartilage. Note the chondrocyte lacunae. The tide mark is the area where the cartilage changes from cartilage to bone.

Based on recent studies, H&E staining does not provide enough sensitivity to accurately assess cell viability. Reliance on H&E staining alone may result in significant under-estimation of the depth of cell death when testing for thermal effects.\(^{5,7}\)
References


7 Kevin Speer, MD, personal correspondence.


13 Molecular Probes, Eugene OR. *Product Information Sheet* MP 03224.

14 Data on file.
Additional Instruction

Prior to performing this technique, consult the Instructions for Use documentation provided with individual components — including indications, contraindications, warnings, cautions, and instructions.

Courtesy of Smith & Nephew, Inc., Endoscopy Division

Caution: U.S. Federal law restricts this device to sale by or on the order of a physician.