Current Applications for Arthroscopic Thermal Surgery

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BASIC SCIENCE

The thermal effect of heat shrinkage on collagen is dependent upon three issues: temperature, time, and tissue (or the quality of the collagen). The effective temperature falls within a range. This effect is dependent on the amount of time the tissue is exposed to that temperature, and is highly dependent upon the collagen cross linking of the tissue which in turn is dependent upon the age of the patient.

The critical temperature range to achieve shrinkage in capsular or ligamentous tissue is 65°-75°C. Very little shrinkage occurs at temperatures less than 65°C. The maximum shrinkage occurs in the temperature range from 70-75°. With increasing age collagen cross links begin to fail which will further influence the effect of heat. Currently, there are two methods used to achieve this heating: the laser and radiofrequency energy. The use of the Holmium YAG laser has declined in recent years primarily because of cost and safety issues. In contrast, radiofrequency energy treatment has gained great acceptance over the past six years with both monopolar and bipolar devices becoming available on the market.

A monopolar device requires both a probe and a grounding plate. Energy from the probe tip passes through tissue to the grounding plate. In tissues that have low impedance, such as joint capsule or ligamentous tissue, sufficient heat penetrates the tissue to cause cell death to a depth of about 3-4 mm. Because articular cartilage has much higher impedance, the energy path actually flows through the irrigation solution resulting in a more limited depth of tissue penetration, usually only 0.4 mm to 0.9 mm. This depth of penetration is highly dependent upon the temperature setting of the probe, the electrical conduction path, and the thermal conductivity of the tissue.

With bipolar probes, the energy passes through the irrigation solution from the probe tip and back to itself. The depth of penetration is from 3 mm to 5 mm in soft tissue, such as joint capsule, with surface ablation and caramelization of the tissue. In articular cartilage, this depth of penetration is from 1.5 mm to 3 mm, but is highly dependent upon the probe temperature, which in turn is controlled by the power applied.

In vivo studies[1] of radiofrequency (RF) energy applications in capsular tissue show an initially significant thermal effect with a significant drop in tissue stiffness and viscoelastic properties that peaks 2 weeks after surgery. Afterwards a gradual improvement occurs to the mechanical properties of the tissue, and by 12 weeks, the tissue regains its normal mechanical properties.

The loss of tissue stiffness reaches a peak of 50% to 60% at 2 weeks, shows considerable healing and a return toward normal stiffness by 6 weeks, but does not actually return to a normal tissue stiffness level until 12 weeks after RF heat application. This same pattern of healing is seen with the viscoelastic properties of tissue which show a reduction up to 6 weeks, and do not return to normal until 12 weeks after surgery. Initially a significant thermal effect is seen histologically which is followed by a highly active cellular response that returns almost, but not entirely, to a normal histologic appearance by 12 weeks after surgery.[1]

Following thermal treatment, large hyalinized regions with pycnotic nuclei and denatured tissue are seen. Two weeks later, the beginnings of a vascular and fibroblastic invasion are observed. There is almost no inflammatory response at this point; rather it is principally a fibroblastic and angiogenic response. By

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6 weeks after thermal application, this angiogenic and fibroblastic response is dramatic with islands of hyalinized, denatured collagen. By 12 weeks, the hyalinized collagen has been completely replaced, although the tissue remains somewhat hypercellular. This response is similar to previously published laser studies.[2-6]

A more extensive cellular response has been reported in studies of RF treated tissue. The RF energy treated the tissue to a depth of 3 to 4 mm in contrast to the 1 mm to 2 mm depth for the laser studies. It takes longer for the larger amount of tissue to be replaced. This tissue heals by replacing the damaged tissue with fibroblasts. These fibroblasts arise from beneath the tissue they replace. This suggests that if radiofrequency heat were applied using a grid pattern, viable fibroblasts would remain between the treated areas. This in turn would enhance or speed postoperative healing. This concept was borne out by a study that showed a significant early effect due to that rapid revascularization and repopulation of the normal tissue of the grid by fibroblasts.[7]

In conclusion, the studies on joint capsule demonstrate that capsular tissue modification can be effectively achieved by RF energy, that shrinkage is temperature dependent, but the depth of penetration is highly power dependent, and that faster healing can be achieved using a grid pattern.

The thermal effects on capsular tissue are different than those on articular cartilage. Collagen denaturation and shrinkage, whether you want to anneal a surface, shrink an ACL, or treat cartilage begins at 65°C and is optimal at 70-75°C. Cell death begins at 45°C, and at 55-60°C all the cells within the tissue that reached that temperature have died. This means that any tissue treated with this temperature must contain dead cells. The goal of femoral chondroplasty is to minimize cell death so that the surface can be treated without killing large numbers of cells deep into that cartilage surface. Capsular shrinkage, in contrast, causes collagen denaturation throughout the tissue and all the denatured tissue is replaced through the healing process. This tissue is replaced in a 6-12 week time frame. In articular cartilage, replacement does not happen. The cartilage loss that occurs at the time of heat application is permanent. Cartilage does not repair itself.

Why then do we even consider using thermal chondroplasty? The reasons proposed are to achieve an accurate debridement without damaging adjacent unaffected tissue, to physically smooth the cartilage in a manner not achievable by mechanical means, to use an arthroscopic technique, and to do this in a manner that ideally reduces inflammation.

Why would thermal chondroplasty reduce inflammation? Normally, in fibrillated cartilage, regardless of the cause, collagen and proteoglycan epitotes are released that go to the synovial membrane. The synovial membrane then releases various substances, including many of the metalloproteinases that cause further degradation of the cartilaginous surface. This creates a cyclic process resulting in more inflammation leading to swelling and pain. Annealing the chondral surface minimizes or reduces the release of epitotes and matrix components that cause inflammation and thereby reduces the pain.

An earlier study on the effect of monopolar RF on partial thickness articular cartilage defects in sheep lead to the conclusion that monopolar RF caused long term chondrocyte death while maintaining a smooth articular surface out to 6 months. In contrast, partial thickness mechanical debridement resulted in progressive fibrillation down to the tidemark in subchondral bone. Full thickness debridement and “microfracture” filled the defect with fibrous connective tissue with small islands of fibrocartilage. This lead to a recommendation against the use of thermal chondroplasty.[8]

This was countered by as study of fresh human cartilage from total knee arthroplasty patients using a bipolar multielectrode wand. Cell viability was evaluated with H&E staining. The conclusion was that the chondrocytes remained viable in the bipolar radiofrequency energy (BRFE) treated areas. A smooth surface could be produced and the acute effect of BRFE indicated it was safe to apply to articular surfaces.[9]

This study was replicated only using confocal laser microscopy in vital cell staining. This study demonstrated a depth of articular cartilage cell death that ranged from 1.5 mm to 2.5 mm. An increased depth of penetration occurred with higher power settings. It was felt that light microscopy could not accurately assess chondrocyte viability and that BRFE created significant chondrocyte death in human articular cartilage with naturally occurring chondromalacia. The warning was made that BRFE posed a danger for creating full thickness articular cartilage death down to and including the subchondral bone.[10]

Markel reports soon to be published studies supporting the conclusion that BRFE causes significantly greater depth of chondrocyte death than monopolar radiofrequency energy (MRFE). Also, even short treatment times of as little as 20 seconds can cause full thickness chondrocyte death in BRFE treated specimens, especially if pathologic thinning of the cartilage has occurred.

What is the most effective treatment time? One study treated a 1 cm^2 area for 5, 10, 15, 20, 30, and 40 seconds with either a BRFE probe or a MRFE probe. A paintbrush treatment pattern was used. Confocal laser microscopy and scanning electron micrographs (SEMs) were used to evaluate the surface. The MRFE probe caused, at 5 seconds, 420 microns depth of cell death which increased to 850 microns at 20 seconds. The BRFE probe caused 920 microns of cell death at 5 seconds which increased to 2 mm at 20 seconds. This differing pattern of increasing cell death held true for longer periods too (30 and 40 seconds). Also, the SEM appearance of the human chondromalacia showed no statistical difference in smoothing, between 10 and 40 seconds, or for either device. The conclusion was that 5 to 10 seconds of treatment does not smooth the surface for either monopolar or bipolar RF energy. A 1-cm^2 area requires 15 seconds to be effectively smoothed.

Also, increasing the irrigation fluid flow increased the tissue cell death. This is because the increased flow actively cools the probe tip. Consequently it takes more energy into the tissue to maintain the tip temperature. With the irrigation fluid at body temperature less energy is required to drive the probe tip than when the irrigation fluid is at room temperature.

Recent studies with body temperature lavage suggest that it may be possible to achieve an equivalent surgical result with thermal treatment or with mechanical debridement. This is because mechanical debridement removes 500 microns of tissue and results in an additional 250 microns of cell death after surgery. Monopolar RF kills 420 microns of cells within the tissue and probably results in the death of another 250 microns depth suggesting an equivalency to mechanical debridement. SEM indicates that a smooth surface may be achieved in 10 seconds, although not as smooth as after 15 seconds. The observation suggests that monopolar RF causes less chondrocyte death in 37°C lavage than in 22°C. This energy difference is in part due to the active cooling of the tip in the lower temperature fluid. Active irrigation flow will have that effect also and result in the need for more energy to maintain the tip temperature. This leads to the recommendation that if monopolar RF is to be selected for chondroplasty, 37°C lavage should be used with no flow or reduced flow.

The data suggest that Bipolar RF energy may cause significant cell damage and that this damage may extend to the underlying subchondral bone. If this is so, should we not be seeing an increasing number of complications reported in the literature? It may be that the integrity of even dead articular cartilage provides some resistance to delamination and that, because of the good articular surface congruity, some time may be required before delamination from full thickness cartilage death begins. Secondly, because of the spotty application of this technique to the condyle, areas with normal viable articular cartilage and bone remain in the treated zones that support the condyle and prevent collapse from occurring. Thirdly, treatment may be in a non-weight bearing area of the femur, which is less susceptible to progressive problems as might be seen in weight bearing area. Finally, there is considerable difficulty distinguishing between the effects of thermal treatment and the natural progression of a disease. It may be that many negative results are being considered the natural progression of a disease rather than a negative result secondary to thermal chondroplasty.

Future considerations should include a determination of whether thermal treatment is a beneficial procedure. Knowing that a smooth surface can be achieved and that this is maintained is not the same as proving that this is the safest device available to achieve this goal.[1,4,5,11-17]

CLINICAL APPLICATIONS

As we know from the basic science, the triple helix of collagen unwinds with heat while maintaining the intermolecular cross-links. This boils down to two physical effects: heat shrinks and weakens tissue. Eventually the weakened tissue will remodel and normal strength be regained. These factors must be considered clinically and present treatment opportunities as well as concerns.

Ankle

Clinically, RF energy can be used to treat several conditions in the ankle. These include ankle instability, meniscoid lesions, and arthrofibrosis. The standard ankle arthroscopy setup includes either a small or standard sized arthroscope with a standard camera setup, shaver blades of different sizes, and interchangeable cannulas. Portal selection and placement is important. The basic working portals are the anteromedial (located medial and anterior to the tibial tendon on the joint line to avoid the saphenous nerve and vein), the anterolateral portal (lateral to the peroneus tertius tendon on the joint line to avoid the superficial peroneal nerve), and the posterolateral portal (lateral to the Achilles' tendon, one cm above the fibular tip avoiding the sural nerve and the short saphenous vein). Inflow can be through the scope and sometimes also through the posterolateral portal.

The technique of portal creation is important to avoid neurovascular injury. Find the joint line with a needle and then inflate the joint. A shallow incision is made in the skin with a 15-blade scalpel and the soft tissue is spread with hemostats down to the joint capsule. This moves the soft tissue out of the way and avoids neurovascular injury. To begin, view anteromedially and instrument anterolaterally. Good water flow and adequate distention are essential. An arthroscopic pump may be used, but with caution to avoid fluid extravasation.

The RF probe can be used to tighten the lateral ankle ligaments similar to a Brostrum procedure. The indications for the procedure include the physical findings of an anterior drawer and a positive talar tilt sign. Clinically there should be a history of two to three significant ankle sprains within a 6 months interval characterized by ecchymosis, pain and swelling. In addition the patient should have failed a six to nine month program of conservative treatment.

The steps for thermal stabilization of the lateral ankle ligaments start with viewing the lateral ligaments through the anteromedial portal. The ankle is everted and dorsiflexed to relax the lateral structures. Any redundant capsule is removed to expose the underlying ligament. The RF probe is inserted through the anterolateral portal and thermal shrinkage starts posteriorly focusing initially on the calcaneofibular ligament and then moving anteriorly to address the anterior talofibular ligament. Postoperatively, the ankle is immobilized and the patient remains non weight bearing for three weeks. A postoperative boot is used until six weeks after surgery. After six weeks, exercises are started using a brace to avoid inversion. From three to six months, sports are allowed with taping and bracing.

Other clinical applications for the ankle include treating arthrofibrosis and meniscoid lesions. Patients who fail to regain motion after trauma despite aggressive physical therapy for several months, are candidates for debridement of adhesions. The hard, dense, posttraumatic scar can be divided and ablated by the RF probe. Afterwards a motorized shaver removes any residual debris and clears the gutters. Another application for the RF probe is shrinking meniscoid lesions at the anterolateral corner of the ankle. This may not be cost effective, however, because a shaver can also remove this tissue just as easily and probably with less expense.

Knee

In the knee, RF can be used to cut tissue, remove tissue, shrinkage tissue, and prepare the ACL/PCL site by exposing the bony landmarks in the knee. Using RF energy facilitates ACL guide wire placement by efficiently removing soft tissue in the area. It especially effective for PCLs. Using the posterior lateral or the posterior medial portal, a 45° or 90° angle RF probe can elevate the capsule from the posterior aspect of the tibia to facilitate graft passing. RF facilitates the removal of soft tissue from the lateral femoral condyle clearing the way for the notchplasty, performing lateral retinacular releases, reaching difficult areas of the meniscus where a mechanical debrider is difficult to insert, lysis of adhesions in cases of arthrofibrosis, and shrinking the medial retinaculum.

Patellofemoral Instability

Arthroscopic surgery permits a careful assessment of patellar tracking, the identification and removal of loose bodies, and the debridement of any patellar articular cartilage lesions associated with patellofemoral instability.

One approach to recurrent patellar instability which is especially helpful for a patient with open growth plates is the medial retinacular plication combined with the lateral retinacular release. Arthroscopic and arthroscopically assisted treatment of the acute patellar dislocation was reported in 1986.[18] The traumatic tear in the medial retinaculum was arthroscopically closed using #0 Vicryl. Although follow up was limited, this demonstrated that such a technique might have clinical usefulness. A later study used an open medial retinacular plication combined with an arthroscopic lateral retinacular release that addressed all patellofemoral instabilities, both acute and chronic.[19] These 24 patients were sutured with PDS and followed for 18 months with good results.

A similar arthroscopic approach can utilize the RF probe to shrink the medial retinaculum and perform a release laterally. Using a grid or strip pattern, the thermal probe starts inferiorly and moves proximally treating tissue from the medial gutter to the medial patella border. Shrinking the medial retinaculum causes it to both thicken and shorten. The tissue is initially weak and activities must be restricted for at least 3 months. However, the diminished pain associated with this technique facilitates the postoperative exercise resulting in less atrophy and a more rapid restoration of quadriceps strength.

The indications for this procedure are multiple (at least three) recurrent dislocations that have failed a thorough course of physical therapy lasting at least three months. The procedure is contraindicated for acute patellar dislocations to allow healing of the medial retinaculum detachment from the medial femoral epicondyle. All medial femoral tenderness should be resolved prior to performing this procedure even in recurrent dislocations. This medial retinacular shrinkage may also be used in conjunction with a distal realignment procedure such as the Elmslie-Trillat.

While our clinical series does not have sufficient follow up to report yet, there are currently 13 patients with an average follow up of 33 months (minimum 12 months) who underwent this procedure. There has been no decline in the success rate using this procedure compared to the comparable open procedure. The advantages of this procedure are the lack of an incision, decreased postoperative pain, and an easier return to full strength. The therapy goes quicker because the patients are more comfortable, and respond to therapy very quickly.

Articular Cartilage

The management of articular cartilage lesions (AC) either partial or full thickness remains controversial. Some lesions are silent and neither progress or produce symptoms. Others as seemingly inconsequential as a soft surface blister may produce significant discomfort. Deeper lesions may cause mechanical, loose body like symptoms and inflammation with associated pain and swelling. These lesions may also increase in size. Fibrillated articular cartilage will continue to propagate even with simple cyclical loading and partial thickness lesions may propagate by delamination and fragmentation or progressive fibrillation. Full thickness grade 4 lesions can expand by continued delamination along the calcific zone.

Surgical Management

The current objective in the treatment of these lesions includes the removal of loose or degenerated cartilage with the objective of leaving as smooth a surface layer as possible. Debriding the cartilage until no further separation can be probed or visualized stabilizes the edges of the lesion. These surgical objectives are currently accomplished with mechanical shavers, hand instruments, or thermally with lasers. Unfortunately these devices are far from optimal. Mechanical debridement removes an excess amount of healthy articular cartilage and may leave an unstable margin. The surface also remains rough and irregular permitting greater matrix permeability with increased water concentration and decreased cartilage stiffness. Lasers were used in an attempt to overcome these shortcomings. Raunset and Lohnert[20,21] reported the results of a randomized clinical trial comparing excimer laser and mechanical debridement in the treatment of Outerbridge[22] grade 2 or 3 lesions of the articular cartilage. In 140 patients, the author found that the laser group had a significant reduction in pain ($p = 0.05$) and reactive synovitis ($p = 0.001$). Despite these encouraging results, the laser has fallen out of favor in arthroscopic surgery because of cost, inconvenience, and safety concerns. Bipolar RF energy (BRFE) appears to work in a fashion similar to lasers. Loose or fibrillated surface cartilage is ablated. The lining of weight bearing collagen on the AC surface is denatured as surface water is vaporized. A smooth concentrated layer of collagen/scar forms as a surface layer (neosurface).

Turner compared the use of a mechanical rotary shaver to a BRFE probe in debriding roughened AC in a sheep model.[23] The sheep were sequentially sacrificed at specific intervals between time 0 and 24 weeks. The cartilage was histologically graded according to the Mankin scoring system and was compared to the control non-treated cartilage. By every measure the BRFE probe was superior to the mechanical shaver. None of the AC specimens treated with the BRFE device, regardless of the time interval used, demonstrated any evidence of chondrocyte death, or osteonecrosis. In fact the mechanical shaver had a statistically higher number of empty lacunae and hypereosinophilia ($p < 0.05$). In a pilot study again comparing the mechanical shaver to a BRFE on roughened sheep articular cartilage, Gamberdela found with electron microscopy that the mechanically debrided surface at three months remained roughened and propagating. In contrast, the BRFE ablated surface remained stable and smooth. No chondrocyte death was found in these animals at three months.

Safety

The use of BRFE on articular cartilage began in 1996.[9] Initially the articular cartilage on the portion of the femoral condyle that was to be removed during the notchplasty segment of an ACL reconstruction was treated. This treated articular cartilage was evaluated histologically using standard staining techniques. The articular cartilage underlying the ablated area demonstrated a zone of injury of approximately 100 to 200 microns with the remainder of the articular cartilage appearing normal. In order to further establish the safety of BRFE in articular cartilage debridement, six fresh femoral condyles from patients undergoing total knee arthroplasty for unicompartmental disease were treated. Patients with inflammatory arthritis or condyles with full thickness loss were excluded.[9] The purpose of this study was to determine the viability of the remaining articular cartilage following ablation of superficial degenerative articular cartilage and to quantify the volume of tissue ablation given the BRFE setting. Each of the specimens was placed in a testing jig simulating the arthroscopic environment including a flow of normal saline.

Areas of degenerated and normal articular cartilage were treated and grossly appearing untreated normal articular cartilage served as the control. A number of staining techniques were employed to evaluate the matrix, ground substance, as well as chondrocytes. The initial appearance of the excavated surfaces where the tissue had been ablated remained smooth and indistinguishable from the control areas including the appearance of the nuclei within lacunae. The healthy appearing cartilage that was treated also demonstrated an area of apparent injury, but the depth did not exceed 200 microns. A direct correlation existed between the amount of tissue ablated and the power setting applied, but no significant increase in the degree of injury was observed. The exposure time and contact pressure of the device was felt to be safe and effective for use on degenerated articular cartilage.[9]

Lu et al. subsequently published two studies regarding the effects of RF energy on articular cartilage. The first study[8] used a monopolar device on sheep articular cartilage and demonstrated full thickness articular cartilage necrosis at time zero and at 6 months. The second study[10] used a live cell-dead cell assay at time zero to determine the viability of human articular cartilage treated with BRFE. They found that BRFE resulted in full thickness red staining and concluded that this indicated that the entire thickness of cartilage and adjacent bone was dead. Several problems exist with this study included the finding by Yetkinler that live/dead cell assay can over simulate cell death by more than 50%.[24] The specimen slides in Lu's studies also show no removal of articular cartilage when the surface was treated which may be inconsistent with appropriate energy application.[8,10] Ball and Amil at the University of California in San Diego reproduced the study using the same viability stains and added GAG synthesis as measured by 35 SO_4 incorporation to measure metabolic activity. They found that the bipolar wand would remove tissue leaving a defect on the articular cartilage surface. The remaining surface was smooth and showed red staining that did not penetrate beyond 200 microns. When they looked at metabolic activity, there was no significant difference between the control and the BRFE treated articular cartilage indicating viability of the remaining articular cartilage.

TECHNIQUE

Proper technique in the debridement of articular cartilage using RF is critical in order to avoid collateral tissue damage. As with any surgical device improper use can cause injury.

Fibrillated Articular Cartilage

In treating fibrillated articular cartilage, a low to mid range setting should be used. The BRFE wand should move continuously over the degenerated cartilage maintaining minimal contact (1-2 mm off of the surface). The fibrillated cartilage will dissolve and in some cases contract leaving a smooth surface. For fragmented articular cartilage or loose flaps of articular cartilage, a mid-range setting seems to work best. A continuous movement of the wand with slight contact with the tissue to be removed is best. Two to three second bursts of energy are utilized while observing the tissue to observe the degree of cartilage ablation. Avoid contact with healthy or normal appearing articular cartilage.

Unstable Edges

For articular cartilage lesions bordered by unstable edges, these edges should be probed to test edge stability. Any cartilage that can be elevated off the surface should be ablated using the technique described. The wand should then be passed along the remaining cleavage plain utilizing a low setting to seal the edge by removing the cleavage defect.

Second Look

Second look experience reveals no detrimental effects with BRFE use on articular cartilage. Six cases where BRFE had been used on articular cartilage underwent repeat arthroscopy greater than 2 years following the BRFE debridement. In one case there was expansion of a grade 4 lesion. The remainder of the cases had new pathology as the reason for arthroscopy. There was no evidence of articular cartilage breakdown or necrosis of the treated areas and palpation of the surface was similar to the surrounding untreated articular cartilage. The use of BRFE in articular cartilage spans five years and more than 500 cases (JU). To date no cases of avascular necrosis, acute articular cartilage breakdown with loose body formation or chronic effusions have been seen.

Clinical Use

Delaminating articular cartilage lesions causing effusions and pain are ideally suited for BRFE treatment. This is especially true of symptomatic intercondylar groove lesions. They are particularly difficult to reach with standard mechanical devices and frequently progress if unstable edges remain. Patients with these lesions (some of which had previously undergone mechanical debridement) have been followed for greater than 18 months in a prospective study. No evidence of progression as documented by MRI has been observed (JU).

Conclusion

The preliminary evidence suggests that the use of BRFE for degenerative articular cartilage debridement appears safe and as effective as mechanical debridement. The benefit of a residual smooth articular cartilage surface, improved surgical access, and minimal collateral damage is attractive. As with any surgical cutting device, improper use including prolonged exposure times on articular cartilage may cause significant damage. Much research still needs to be done especially for optimal power settings, and the mechanical alterations that occur in the treated articular cartilage.

Shoulder

While there are many studies that look at the time zero mechanical data of thermal energy treatment effects on collagen and articular cartilage, there is less available literature on the clinical effects over time. There may be little correlation between time zero in vitro mechanical data and clinical outcome.[25] We do know that heated collagen shortens and that the temperatures required accomplishing this (65°C) are far higher than the temperatures at which cell death occurs (45°C).[6] This heated killed tissue becomes necrotic and for this dead tissue to become reconstituted, substantial remodeling will be required.

Hecht et al[15] have demonstrated the extensive degradation of mechanical properties in this tissue which slowly reconstitutes itself over a period of months. Arnoczky[25,26] has similar data with rabbit patellar tendons. Schulz et al[27] showed similar results, with reconstitution of only 84% of tissue strength at 12 weeks post thermal treatment. The initially optimistic evaluation by Hayashi of biopsies in 1995[2] was later tempered when reporting a "persistent synovial, cellular, and vascular reaction even after 1 year postoperatively, the cause of which is unclear."[3]

At this point there are only a few clinical studies using this technology. Two techniques are currently being performed: pure thermal techniques for multidirectional instability without mechanical lesions and mixed thermal plus mechanical fixation techniques for those patients with Bankart or SLAP lesions. Variable patient demographics, commingling lax patients, subluxators, and dislocators, and varying techniques makes assessment of these preliminary reports difficult. Thermally necrosing one's suture line would not seem particularly desirable. Shrinking unattached tissue, that is using thermal shrinkage without securely repairing the Bankart lesion to the glenoid, seems mechanically undesirable as well.

Some studies report only thermal treatment[28-34] without mixing techniques. Unfortunately with this group of manuscripts, it is difficult to differentiate dislocating patients from both subluxating patients and patients with pain ascribed to increased joint translation. Success rates vary tremendously from 70%,[30] 76%[29] to virtually 100%.[29] Why these results are so different is unclear. While many of these authors feel that these results are equal to traditional suture techniques, published studies with traditional arthroscopic suture techniques[35-39] or open techniques[40-47] would suggest otherwise. The second technique uses thermal capsulorrhaphy to augment suture reconstruction of Bankart or SLAP lesions in the shoulder.[48-55] While these techniques have been purported to show improvement over traditional arthroscopic suturing techniques, current techniques have shown similar results without thermal treatment[38,39] especially with interval closure.

As yet there are no well-designed studies that suggest thermal capsulorrhaphy is of significant benefit over traditional suture capsulorrhaphy in the shoulder. Prospective, randomized studies are lacking. The disclosed and undisclosed financial interest of the surgeons who presented early data for this technique remains a concern. The laboratory data are also worrisome because of the extensive time intervals needed for the treated tissue to reconstitute its mechanical properties in vivo.[15,26,56] There are very limited post-

TABLE 1. *Comparison of Complication of Arthroscopic Suture Versus Thermal Capsulorrhaphy*

	Arthroscopic Suture	Thermal
Recurrence	8-15%	0-47%
Stiffness	0-6%	10%
Axillary nerve injury	Not reported	8% ? unknown
Capsular necrosis	Not reported	Unknown

operative biopsy results. These limited data give indications that the tissue may take up to two years to be fully reconstituted.[3] Many experienced authors have expressed concerns with the widespread release of this technique with little clinical data to support it.[28,57,58]

Why is there so much interest? The advantage seems to be that the thermal techniques are easier; however they are not without complications. Complications have been noted in four areas secondary to thermal capsulorrhaphy: 1) recurrence 2) stiffness 3) axillary nerve injury 4) and capsular necrosis. An additional group might be those with a "wrong diagnosis" or the patients who in retrospect were inappropriate for any capsulorrhaphy procedure, suture or thermal (Table 1). Many of these complications are unique to thermal techniques.

The most frequent complication with shoulder stabilization using arthroscopic suture techniques is recurrent instability. Recurrence after a thermal procedure has been reported to occur between 0% and 47%. However, the data are difficult to sort out as previously noted due to differences in patient populations, treatment parameters, and treated pathology.

While stiffness does occur with conventional arthroscopic techniques, it seems rare.[35,36,38,39] Stiffness can occur with thermal capsulorrhaphy but the rates are unknown, with many thermal capsulorrhaphy studies failing to report this complication. Cuillo reports a post thermal capsulorrhaphy stiffness rate of 10%, as does Miniacci.[61] Six patients were biopsied by Hayashi et al with late shoulder stiffness[4] but it is unclear from what size population they were drawn. This group reported a significant synovial reaction that persisted even at one year in these patients, the cause of which was unknown.[4] Stiffness that is refractory to subsequent treatment seems unique to thermal techniques, as the orthopedist's experience with capsular release in the non-thermally treated patient has generally been good.

Axillary nerve injuries are theoretically possible with conventional surgery, but lab studies have shown that this is also unlikely.[59] Temporary axillary nerve injury with thermal treatment has been reported to occur in 8% by D'Alessandro,[30] Greis et al,[60] and Miniaci et al[61]; permanent nerve injuries have also been reported (Savoie, personal communication). Axillary nerve injuries can occur even with experienced surgeons. The basic science data vary but there is some concern about the possibility from thermal damage[63] due to temperature changes at the nerve despite appropriate technique. While many of these injuries spontaneously resolve, they carry morbidity,[60,61] and have not been unreported with arthroscopic suturing techniques.

Several authors report capsular necrosis[39,57,61,64] but again the rate is unknown. While unreported with suture techniques, this clearly does occur with some frequency after thermal shoulder capsulorrhaphy and creates a significant technical problem with subsequent revision surgery. Necrosis of other thermally treated tissues has been noted as well.[64] Applying the thermal treatment using a grid or stripe pattern has been proposed to correct this problem,[51,61] but whether this will avoid capsular necrosis is unknown. If the capsular necrosis is extensive enough it may require either an allograft or a distant site autograft to effectively reconstruct the capsule. Since any technique needs to anticipate failure, a technique that compromises a later bail out procedure creates a significant problem.

While a wrong diagnosis is not a failure of the technique per se, the ease of application of the thermal techniques will certainly result in patients having thermal treatment for whom capsulorrhaphy of any type is inappropriate. Separating the patient with asymptomatic laxity from a patient with symptomatic instability remains the ultimate challenge to the shoulder clinician.

Four studies have dealt specifically with the problem of thermal technique complications. Jensen reports open revision of a series of 11 failed thermal capsulorrhaphy patients eight with thin friable tissue, and two with frank capsular necrosis.[65] Post thermal surgery biceps tendon subluxation was noted in two. For the patients with capsular necrosis a careful reconstruction was adequate and donor tissue not required. One of the authors (SW) has a clinical experience with 15 patients reoperated upon for failed thermal capsulorrhaphy with 100% arthroscopic evaluation of the post thermal patients.[66] No axillary nerve injuries were noted, but recurrent instability, capsular necrosis, and stiffness refractory to subsequent arthroscopic release were reported. Of note is the fact that in this series the worst outcomes were in the stiff patients. Ten of these had recurrent dislocations and two of these were found to have severe capsular necrosis. There were no nerve injuries and one subluxing biceps tendon. Four demonstrated stiffness, but only one obtained a reasonable relief of his symptoms with a capsular release. One patient with shoulder stiffness (a former professional pitcher) reported that his career was ended by his thermal procedure. Miniacci reports a series of interest in that all procedures were performed for one diagnosis (multidirectional instability) by one surgeon.[61] He showed a 47% failure rate with a 10% incidence of stiffness and a 21% incidence of axillary nerve injury that was fortunately only temporary. Sperling et al noted that multiple recurrences, prior surgery, contact sports, associated injuries requiring repair, and multidirectional instability were relative contraindications for this technique.[67]

If confronted with a patient who has failed thermal capsulorrhaphy several steps should be taken before any salvage procedure is performed. First, obtain a preoperative EMG to evaluate and document the status of the axillary nerve. Next, be certain to anticipate the potential need for donor tissue for the reconstruction if there is insufficient remaining native tissue. Consider that capsular necrosis will usually make an arthroscopic revision impossible. Post thermal adhesive capsulitis is a real problem. For these patients, an arthroscopic release is not universally successful. Be certain to warn patients to anticipate a lengthy and possibly incomplete recovery.

In summary, while early reports are encouraging, prospective, comparative studies of any type are lacking at this time. Benefits at this time seem to be limited to ease of application over more traditional suture techniques. Little has been published to demonstrate a clinical advantage of thermal energy over other techniques and there are reported disadvantages. The traditional arthroscopic suturing techniques at this time offer all the advantages without the risks of axillary nerve injury, capsular necrosis, and apparently with less stiffness. Until the outcomes and complication rates are clearly defined by appropriate studies, it may be prudent to take the time to master the admittedly more difficult arthroscopic suture techniques rather than considering thermal capsulorrhaphy.

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