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The Effects of Radiofrequency Energy Devices on Achilles Tendinosis: A Case Report and Literature Review

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Thermal surgical devices have broadened their scope from general surgery to orthopedic and podiatric surgery. Radiofrequency technology has been utilized in ligamentous, fascial, and tendinous applications without supportive basic science research and long term clinical studies. The purpose of the current study is to present a case of Achilles tendinosis exacerbated by radiofrequency energy. The included discussion and literature review heightens the readers' understanding of the mechanisms by which radiofrequency energy works and the associated histological and biomechanical sequela.

Key words: Microdebridement, Thermal, Ablation, Microtenotomy, Electrosurgery

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With the advent of thermal energy as a means to stimulate soft tissue contraction and neovascularization, there has been considerable interest in its use to treat a variety of musculoskeletal problems. Initially applied with laser technology, thermal devices have evolved to utilize radiofrequency energy. The use of radiofrequency thermal devices in capsular instability of the shoulder has been greeted with transient success.[1,2] Proponents have mentioned ease of use, a minimally invasive nature, and decreased post-operative immobilization making the radiofrequency technique a far-sighted attractive alternative to conventional open procedures.[3,4]

Numerous *in vivo* and *in vitro* studies have investigated the biology and biomechanics of thermally modified tissues without consensus towards efficacy.[5-10]

Regardless, the scope of thermal energy devices has expanded to ligamentous, fascial, and tendinous pathologies, though their use has not yet been substantiated with long term studies. The purpose of this report is to present a case of Achilles tendinosis exacerbated by radiofrequency energy treatments.

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Figure 1 Pinpoint hyperpigmentation denoting radiofrequency probe application and hockey-stick incision placement.

Figure 2 Loss of acute definition of Achilles tendon with prominent posterior bulbous mass.

Case Report

A 69 year-old female who was complaining of insertional Achilles tendon pain underwent radiofrequency ablation of the Achilles tendon with a bipolar single electrode radiofrequency-based probe (Topaz® Microdebrider; ArthroCare, Austin, TX) at an outside facility. The patient related that her pain had markedly increased since the procedure. Three months prior to the surgery, she experienced pain with moderate ambulation; after the surgery, her pain significantly exacerbated to the level of excruciating pain with each step. Surgical reports from the outside facility reported the radiofrequency treatment was applied to the distal 10cm of the Achilles tendon.

Physical exam denoted over 40 pinpoint areas of hyperpigmentation over the Achilles tendon associated with known application of the bipolar single electrode radiofrequency-based probe. (Fig. 1) An exquisitely tender bulbous mass visible clinically and on magnetic resonance imaging (MRI) was present at Achilles tendon insertion. (Fig. 2)

Pain was exacerbated with slight ankle dorsiflexion. Biomechanically, the patient presented with an equinus deformity during knee flexion and extension. MRI indicated severe tendinosis of the distal 6.6 cm leading to the calcaneal attachment with abnormal anterior convexity. MRI demonstrated partial tears throughout the Achilles tendon and calcaneal marrow edema with concomitant erosive changes. (Fig. 3) A discussion to including debridement and repair with cadaveric Achilles graft supplementation was planned and all consents for the procedure were signed by the patient.

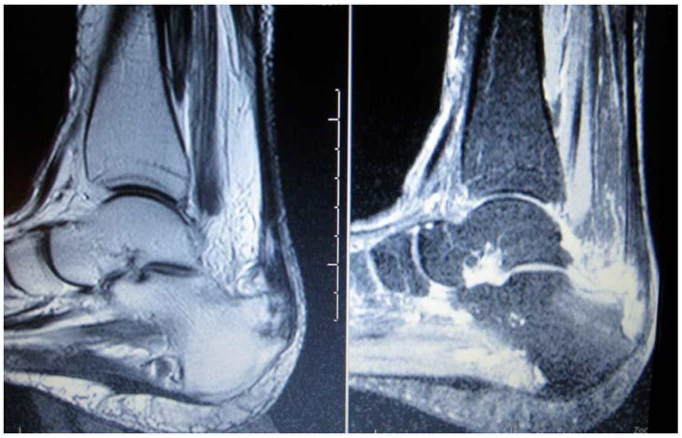

Figure 3 Abnormal Achilles tendon contours with heavy myxoid degeneration and significant subcortical marrow edema.

Surgical Findings

A 10cm posterior longitudinal incision was made medial to the Achilles tendon and over the inferior calcaneus, the incision curved in lateral direction parallel to relaxed skin tension lines. The skin and subcutaneous tissue were incised and a fusiform mass appeared to occupy several centimeters of the distal and insertional Achilles tendon. (Fig. 4)

The paratenon was scant and atrophic with multiple adhesions to the underlying Achilles tendon and the circumferential fibrotic exuberance at the insertion. The Achilles tendon appeared to have a yellow tinge and fibers of no distinct orientation. The myxoid degenerated tendon encompassing over 70% of its stock was resected and sent for pathological examination. (Fig. 5) Reports later confirmed the presence of multiple foci of collagen degeneration, heavy mucoid matrix, areas of entire necrosis with apoptosis within the specimens. Multiple insertional calcific masses were resected from within the tendon. (Fig. 6) The circumferential fat was removed from the retrocalcaneal bursa displaying chronic inflammation on MRI.

Figure 4 Fusiform thickness with myxoid degeneration with heavy circumferential fibrosis and scant paratenon occupying distal several centimeters of Achilles tendon.

Throughout resection, the medial and lateral subcutaneous attachments running along side of the Achilles tendon and the calcaneal insertional area were preserved. After the intratendinous calcific deposits and the superior edge of the calcaneal enthesiophytes were resected, a cadaveric Achilles tendon was prepared for incorporation.

Figure 5 Degenerated tendon sent for histopathologic evaluation reported to have areas of total necrosis.

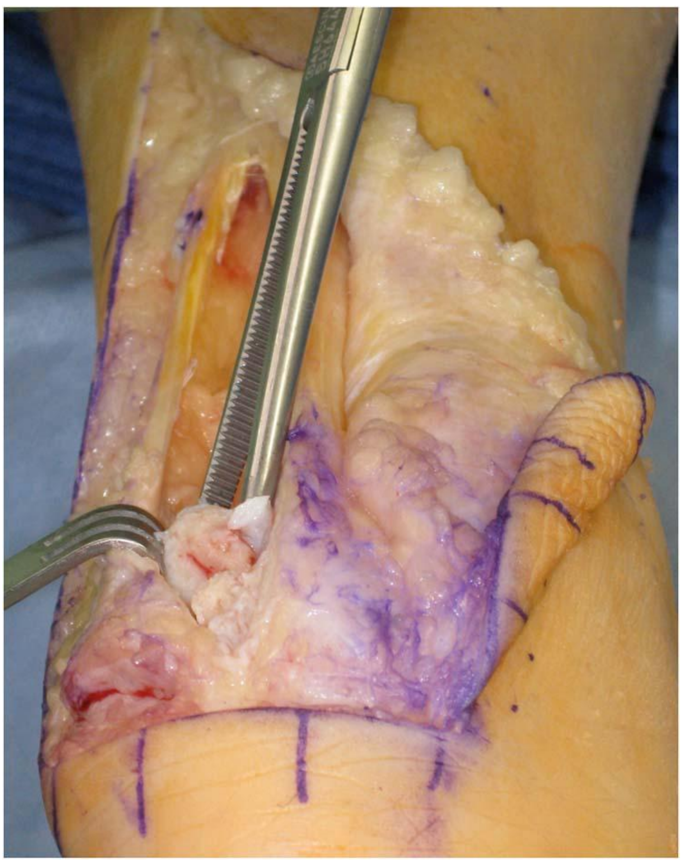

Figure 6 Calcific masses seeded within inflammatory sites in insertional Achilles tendon.

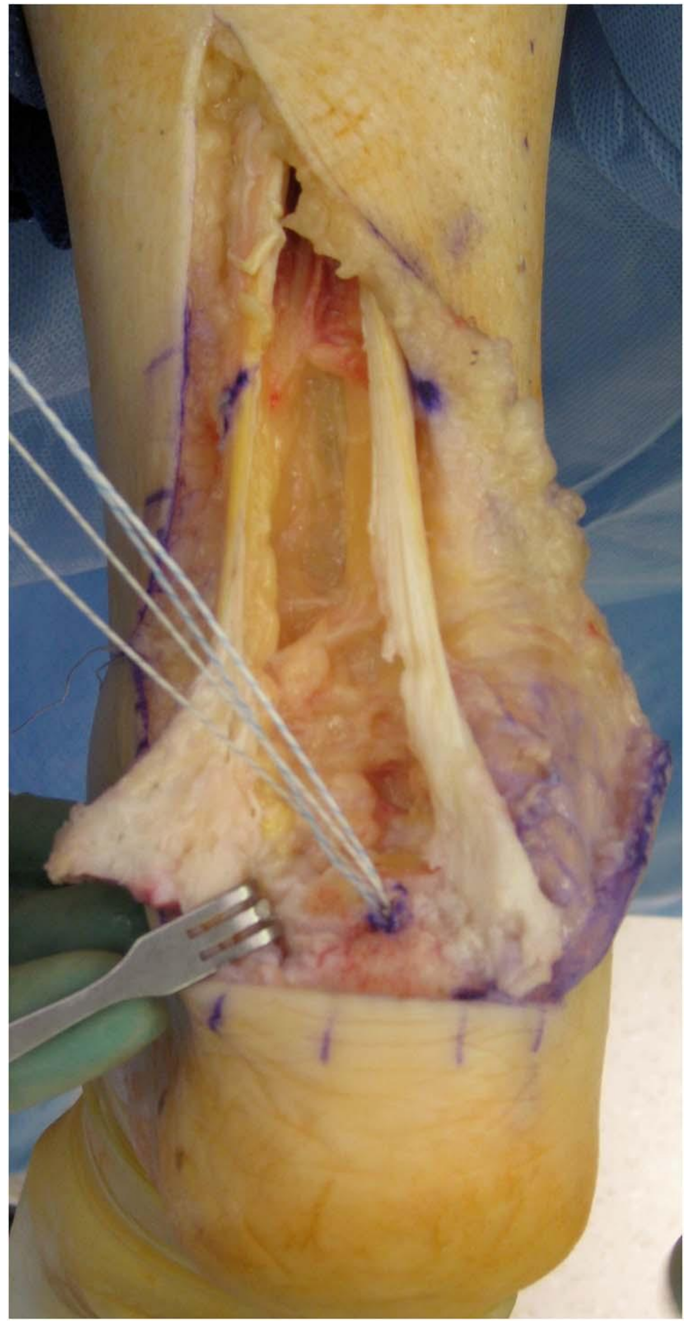

Figure 7 Preservation of medial and lateral soft tissue attachments to Achilles tendon and application of corkscrew anchor within central calcaneus.

A corkscrew anchor was placed in the posterior central aspect of the calcaneus deep to the foreseeable cadaveric Achilles tendon insertion. (Fig. 7) With #2 nonabsorbable polyblend suture, cadaveric Achilles tendon was sutured between the medial and lateral remnant tendon with the graft held in tension and the ankle in slight plantarflexion.

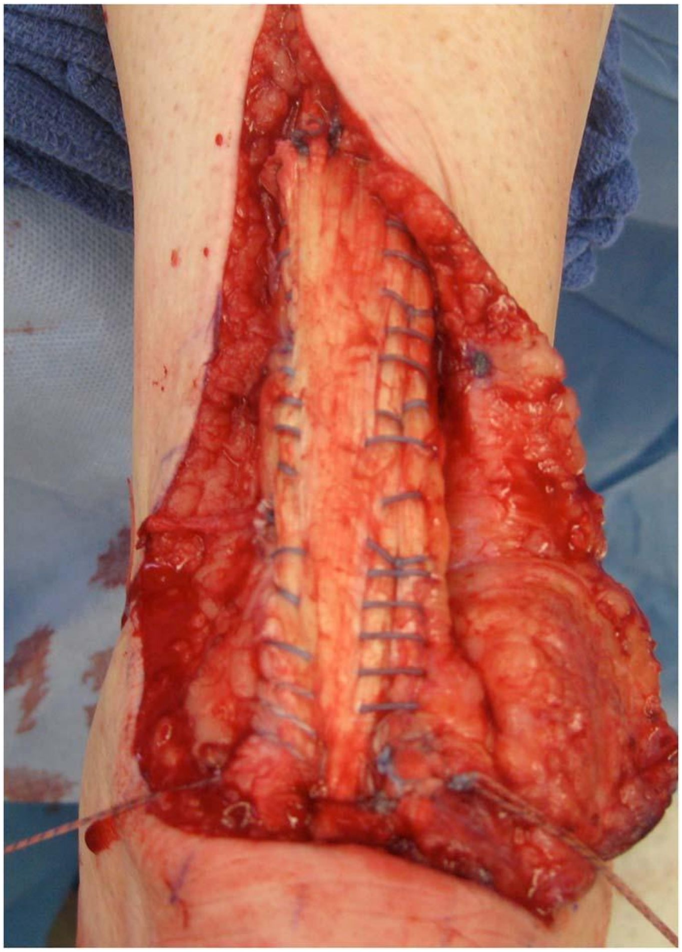

Figure 8 Krackow stitch anchoring cadaveric Achilles tendon graft to remnant medial and lateral Achilles tendon borders sown in slight plantarflexion. Further reinforcement with bone anchors and to circumferential soft tissue increases stability of construct. Release of tourniquet depicts ability of adequately vascularized cadaveric graft.

Using the #2 Force Fiber® (Tornier, Edina, MN) from the 5mm corkscrew Insite™ anchor (Tornier, Edina, MN), a Krackow stitch was applied to the inferior 3cm of the medial and lateral aspects of the Achilles tendon graft.

Two medial strands were anchored into a secondary medial Piton® anchor (Tornier, Edina, MN) and two lateral strands were anchored into a tertiary lateral Piton® anchor. (Fig. 8) The Piton® anchors were approximately 2cm apart and 1cm inferior and equidistant from the central corkscrew anchor to increase bone-tendon interface. Care was taken to ensure ankle resting position remained in slight plantarflexion. (Fig. 9)

Figure 9 Lateral view denoting amount of tension present in resting Achilles tendon.

After tendon and circumferential soft tissue attachments were reinforced, the surgical site was flushed and closed in the usual technique. A posterior splint was applied. Postoperative care consisted being non-weightbearing for 8 weeks with a gradual transition from range of motion exercises to weightbearing. Patient continues to demonstrate improved pain and ease with ambulation.

Discussion

The initial surgical use of thermal delivery systems involved cutting and coagulating tissue. The concept of tissue welding was introduced with the ability of heat to divide and seal with interdigitations. Thermal welding has long-standing implementation in transmyocardial revascularization, gastric bypass, hemorrhoidectomy, and cholelithiasis among other visceral procedures.[11-13] In the paucity of orthopedic and podiatric literature, thermal devices have been applied in chondromalacia, patellar tendinosis, rotator cuff tears, lateral ankle instability, plantar fasciosis, and Achilles tendinopathy.[1,2,9,14-24] The mechanism of radiofrequency electrosurgery is similar to a surgical cautery, which can coagulate at high voltages or cut and ablate at low voltages.[46]

Macroscopically, the active electrode vaporizes water in the underlying soft tissue dissipating the density and creating a *"shrinking"* effect.[5] As heat disorients the linear connective tissue pattern and produces swelling across the transverse axis, the modification in tissue structure is visualized as additional "shrinking".[5,25,26]

More recently, radiofrequency devices have been used in thermal delivery systems to provide the beneficial effects of heat while mitigating detrimental thermal penetration. Radiofrequency energy is a form of electromagnetic energy that operates by producing localized heat in an ionized field.[30] The bipolar single electrode radiofrequency-based probe (Topaz® MicroDebrider; ArthroCare, Austin, TX) is advertised to work through "non-thermal" means though heat is an inherent part of the shrinkage mechanism.[18,30,31] In radiofrequency, heat is generated extrinsically through electrolyte oscillation in an ionized field rather than intrinsically from the probe itself.[18,30-33] Any ultrastructural alteration of collagen architecture utilizes heat as the predominant mechanism.[27] In addition, the radiofrequency-based probe allegedly accomplishes volumetric reduction and surface contouring through debridement though this claim has not been substantiated.[34-37]

The term "debridement" may be a misrepresentation of the biologic remodeling process, seeing as there is no removal of devitalized tissue.[34] However, radiofrequency energy can smooth and contour circumferential tissue irregularities.[31,34] A review of several studies evaluating the effect of radiofrequency on articular cartilage demonstrated smoothing of cartilaginous fibrillations with no evidence of debridement suggesting that radiofrequency energy "anneals" rather than "debrides".[19,20,36-38]

Arthroscopic examination during radiofrequency treatments demonstrate melting of the fine fronds protruding from the articular surface although deeper clefts remained.[39] With longer treatments (15 seconds) the color of cartilage changed to light gray, then to light yellow, and eventually to brown.[39] Color change is no doubt an indication of chondrocyte viability.[18,36,37] Thermally induced volumetric reduction and surface contouring through radiofrequency energy are well-documented phenomenons though the molecular mechanism still require elucidation.[30]

The architectural denaturing of collagen molecule is theorized to cause shrinkage and subsequent fibroplasia, neovasularization, and fibrovascular formation.[30,38] However, *in vivo* histologic studies have found the contrary. Similar to the pathology report presented with the present case report, post-thermal tissue analysis demonstrates inflammatory cell infiltration, vascular stagnation, and necrosis of fibroblasts, smooth muscle, synovial cells, and endothelial cells.[17,38,40] Repeat histological examinations report persistent inflammation and reactivity several months into the postoperative period.[40] MRIs show periarticular swelling with effusion, extensive abnormal signal penetrating the subchondral marrow, and development of subcortical cysts post-radiofrequency treatment similar to the findings of the current case report.[41,42]

Thermal injuries, in particular, are associated with a high degree of cell death and matrix alteration.[43] Consequently, the inflammatory response generated in response to thermal injury is markedly protracted compared to traumatic insults.[43] Thus a prolonged post-operative period is expected from the heat generated in radiofrequency treatments. Compounding the effect of heat, tendons, ligaments, and other tissues of a denser, less aqueous composition harbor heat for longer periods of time.[44] Cool saline irrigation is applied to mitigate the thermal effects.[44] However, the ablated tissue acts as a heat sink resulting in cellular death and necrosis.[45] In the thermal algorithm utilized by radiofrequency, a temperature of at least 65C is required to cause shrinkage despite the fact that any temperature over 45C is lethal to most cells.[11,18,33,43] Optimal shrinkage is noted to occur in the range of 60C to 80C.[6,30] Consequently, a significant portion of visibly shrunken tissue is necrotic. Focal heat generated by radiofrequency produces necrosis, fibrosis, and adhesions and clinically results in decreased structural integrity as seen in the current study.[9]

Deformation of tissue under constant loads or "creep" is a primary mechanism of laxity after thermal reconstructive surgery.[28] Mechanical testing post-thermal treatment verifies weakening of the intrinsic structural properties of the tissue itself.[46]

Ligamentous structures were nearly normal initially and became attenuated in the following weeks.[23,28,30,46,47] Prior to the thermal insult, initially damaged tissues including scars, are noted to creep more than intact noninjured ligaments.[48] Radiofrequency treatments themselves are noted to compound the biomechanically inferior results.[46] Studies have suggested a minimum of twelve weeks for the thermally modified tissue to commence recovery of biomechanical properties.[28,49] However, collagen healing and maturation takes three to four months.[6] With early rehabilitation regimens, collagen tissue is associated with thinness, elongation, weakness, and attenuation.[9,21,28] Capsular repairs have resulted in multidirectional or stretch-type instability.[7,50] Consequently radiofrequency *"tightening"* actually weakens the anisotropic capsular and ligamentous structures, sustaining loads from multiple directions.[17,28,40,51] Heat-applied tendons demonstrate a significant one-third decrease in load-to-failure compared to controls.[51] These poor biomechanical results associated with thermal procedures often require revisional surgery which is noted to be more difficult secondary to poor tissue quality and heavy scarring.[6] The clinical loss of stiffness and inherent stability appear to be concomitant with radiofrequency-generated surgery.[28,30]

Histological evidence and biomechanical studies antagonize anecdotal speculation of neovascularization and increased structural strength. Consequently, thermal procedures are associated with a higher percentage of failures than conventional capsular and ligamentous stabilization procedures.[2,6,8,52] Furthermore, studies maintaining a nine month to five year follow-up period reveal a substantial 37-47% failure rate involving recurrent joint instability, chondrolysis, capsular thinning, heavy scarring, and tissue necrosis.[2,6,9,17,19,20,22,45,52-56] These among other published complications have subdued the initial wave of enthusiasm for surgical thermal devices.[57] The findings of the present report support previously published complications in other relevant sites and structures. Nonetheless, these findings should be interpreted in light of several limitations.

Due to the single patient case report, it may not be possible to fully extrapolate these findings to all patients who endure tendon surgery utilizing radiofrequency technology. Also, the degree of pre-existing pathology in the current study cannot be determined. However, according to patient history and the severe abnormality visualized during surgery, on MRI, and in histopathologic analysis, this patient's Achilles tendon pathology was markedly and acutely exacerbated by the radiofrequency application.

Conclusion

The exact mechanism of collagen destruction resulting in thermal shrinkage is less than poorly understood. Furthermore, no studies have specified the exact technique, amount of energy, threshold for coagulation versus ablation, or type of tissue for effectual coagulation.[2] Indications and results have been anecdotal with capsular instability, chondronecrosis, tendinopathy, ligamentous laxity, and avascular necrosis as major documented complications.[6,10,21,28,37,41,42] The clinicians' focus of literature reviews should be directed towards the additional information presented with each study and how it plays into the risk-benefit ratio of radiofrequency generated thermal surgery. These procedures are increasing in usage and becoming an adjunctive or mainstay surgical technique without proper supportive research. A true understanding of the clinical implications of using radiofrequency necessitates more basic science and clinical studies. With its future in ligamentous, fascial, and tendinous pathology in question, further evaluation is necessary to establish safety and efficacy of radiofrequency in orthopedic and podiatric surgery.

References

1. Taverna E, Battistella F, Sansone V, Perfetti C, Tasto J. Radiofrequency-based plasma microtenotomy compared with arthroscopic subacromial decompression yields equivalent outcomes in rotator cuff tendinosis. Arthroscopy 2007 23: 1042-1051. [PubMed]
2. Tibone JE, McMahon PJ, Shrader TA, Sandusky MD, Lee TQ. Glenohumeral joint translation after arthroscopic nonablative, thermal capsuloplasty with a laser. Am J Sports Med 1998 26: 495-498. [PubMed]
3. Menendez M, Ishihara A, Weisbrode S, Bertone A. Radiofrequency energy on cortical bone and soft tissue: a pilot study. Clin Ortho Rel Res 2010 468: 1157-1164. [PubMed]
4. Yeap EJ, Chong KW, Yeo W, Rikhraj IS. Radiofrequency coblation for chronic foot and ankle tendinosis. J Ortho Surg 2009 17: 325-330. [PubMed]
5. Arnoczky S, Aksan A. Thermal modification of connective tissue: basic science considerations and clinical implications. J Am Acad Orthop Surg 2000 8: 305-313. [PubMed]

6. D'Alessandro DF, Bradley JP, Fleischli JE, Conner PM. Prospective evaluation of capsulorrhaphy for shoulder instability: indications and results, two to five year follow-up. Am J Sports Med 2004 32: 21-33.[PubMed]
7. Fitzgerald BT, Watson BT, Lapoint JM: The use of thermal capsulorrhaphy in the treatment of multidirectional instability. J Shoulder Elbow Surg 2002 11: 108-113.[PubMed]
8. Frostick SP, Sinopidis C, Al Maskari S, Gibson J, Kemp GJ, Richmond JC. Arthroscopic capsular shrinkage of the shoulder for the treatment of patients with multidirectional instability: minimum 2-year follow-up. Arthroscopy 2003 19: 227-233, 2003. [PubMed]
9. Miniaci A, McBirnie J. Thermal capsular shrinkage for treatment of multidirectional instability of the shoulder. JBJS 2003 85A: 2283-2287. [PubMed]
10. Noonan TJ, Tokish JM, Briggs KK, Hawkins RJ. Laser-assisted thermal capsulorrhaphy. Arthroscopy 2003 19: 815-819. [PubMed]
11. Himpens J, Leman G, Sonneville T. Laparoscopic Roux-en-Y gastric bypass performed without staples. Surg Endoscopy 2005 19: 1003. [PubMed]
12. Oz MC, Bass LS, Popp HW, Chuck RS, Johnson JP, Trokel SL, Treat MR. In vitro comparison of thulium-holmium-chromium: YAG and argon ion lasers for welding of biliary tissue. Lasers Surg Med 1989 9: 248-253. [PubMed]
13. Sayfan J, Becker A, Koltun L. Sutureless closed hemorrhoidectomy. a new technique. Ann Surg 2001 234: 21-24. [PubMed]
14. Deol P, Philbin T. Bipolar radiofrequency microtenotomy for chronic Achilles tendinosis. Oper Tech Orthop 2008 18: 254-258.
15. Fink B, Mizel MS. What's new in foot and ankle surgery. JBJS 2002 84A: 504-509.[PubMed]
16. Hayashi K, Thabit G, Massa KL, Bogdanske JJ, Cooley AJ, Orwin JF, Markel MD. The effect of thermal heating on the length and histologic properties of the glenohumeral joint capsule. Am J Sports Med 1997 25: 107-112. [PubMed]
17. Hayashi K, Markel MD. Thermal capsulorrhaphy treatment of shoulder instability: basic science. Clin Orthop Rel Res 2001 390: 59-72. [PubMed]
18. Kaplan LD, Chu CR, Bradley JP, Fu FH, Studer RK. Recovery of chondrocyte metabolic activity after thermal exposure. Am J Sports Med 2003 31: 392-398. [PubMed]
19. Lu Y, Hayashi K, Hecht P, Fanton GS, Thabit III G, Markel MD: Bipolar radiofrequency energy on partial thickness defects of articular cartilage. Orthop Res Soc 2000 45: 799.
20. Lu Y, Hayashi K, Hecht P, Fanton GS, Thabit G III, Cooley AJ, Edwards RB, Markel MD: The effect of monopolar radiofrequency energy on partial-thickness defects of articular cartilage. Arthroscopy 2000 16: 527-536. [PubMed]
21. Ohtoshi K, Kimura M, Kobayashi Y, Higuchi H, Kikuchi S. Arthroscopic thermal shrinkage for hypermobile lateral meniscus. Am J Sports Med 2004 32: 1297-1301. [PubMed]
22. Park HB, Yokota A, Gill HS, Rassi GE, McFarland EG. Revision surgery for failed thermal capsulorrhaphy. Am J Sports Med 2005 33: 1321-1326. [PubMed]
23. Silver WP, Creighton RA, Triantafillopoulos IK, Devkota AC, Weinhold PS, Karas SG. Thermal microdebridement does not affect the time zero biomechanical properties of human patellar tendons. Am J Sports Med 2004 32: 1946-1952. [PubMed]
24. Tasto JP. The use of bipolar radiofrequency microtenotomy in the treatment of chronic tendinosis in the foot and ankle. Tech Foot Ankle Surg 2006 5:110-116.
25. Sherk HH, Vangsness CT, Thabit G, Jackson RW. Electromagnetic surgical devices in orthopaedics: lasers and radiofrequency. JBJS 2002 84A: 675-681. [PubMed]
26. Allain JC, Le Lous M, Cohen-Solal L, Bazin S, Maroteaux P. Isometric tensions developed during the hydrothermal swelling of rat skin. Connect Tissue Res 1980 7:127-133.[PubMed]
27. Hayashi K, Thabit G, Bogdanske JJ, Mascio LN, Markel MD. The effect non-ablative laser energy on the ultrastructure of joint capsular collagen. Arthroscopy 1996 12: 474-481.[PubMed]
28. Wallace AL, Hollinshead RM, Frank CB. Creep behavior of a rabbit model of ligament laxity after electrothermal shrinkage in vivo. Am J Sports Med 2002 30: 98-102.[PubMed]
29. Flory PJ, Garrett RR. Phase transitions in collagen and gelatin systems. J Am Chem Soc 1958 80: 4836-4845.
30. Hecht P, Hayashi K, Lu Y, Fanton GS, Thabit III G, Venderby Jr R, Markel MD. Monopolar radiofrequency energy effects on joint capsular tissue: potential treatment for joint instability. An in vivo mechanical, morphological, and biochemical study using an ovine model. Am J Sports Med 1999 27: 761-771. [PubMed]
31. Edwards III RB, Markel MD. Radiofrequency energy treatment effects on articular cartilage. Oper Tech Orthop 2001 11: 96-104.
32. Stalder KR, Woloszko J, Brown IG, Smith CD. Repetitive plasma discharges in saline solutions. Appl Phys (Letter) 2001 79: 4503-4505.
33. Uribe JW, Sgaglione NA. The use of radiofrequency devices for chondral debridement. Sports Medicine Arthroscopy Rev 2003 11: 214-221.
34. Amiel D, Ball ST, Tasto JP. Chondrocyte viability and metabolic activity after treatment of bovine articular cartilage with bipolar radiofrequency: an in vitro study. Arthroscopy 2004 20: 503-510. [PubMed]
35. Edwards III RB, Lu Y, Nho S, Cole BJ, Markel MD. Thermal chondroplasty of chondromalacic human cartilage: An ex vivo comparison of bipolar and monopolar radiofrequency devices. Am J Sports Med 2002 30: 90-97. [PubMed]
36. Lu Y, Edwards RB III, Cole BJ, Markel MD. Thermal chondroplasty with radiofrequency energy: An in vitro comparison of bipolar and monopolar radiofrequency devices. Am J Sports Med 2001 30: 90-97. [PubMed]
37. Lu Y, Edwards RB III, Kalscheur VL, Nho S, Cole BJ, Markel MD: Effect of bipolar radiofrequency energy on human articular cartilage: Comparison of confocal laser microscopy and light microscopy. Arthroscopy 2001 17: 117-123. [PubMed]
38. Hecht P, Hayashi K, Cooley AJ, Lu Y, Fenton GS, Thabit G, Markel MD. The thermal effect of monopolar radiofrequency energy on the properties of joint capsule: an in vivo histologic study using a sheep model. Am J Sports Med 1998 26: 808-814.[PubMed]
39. Lu Y, Edwards RB III, Nho S, Heiner JP, Cole BJ, Markel MD. Thermal chondroplasty with bipolar and monopolar radiofrequency energy: effect of treatment time on chondrocyte death and surface contouring. Arthroscopy 2002 18: 779-788. [PubMed]
40. Hayashi K, Massa KL, Thabit III G, Fanton GS, Dillingham MF, Gilchrist KW, Markel MD. Histologic evaluation of glenohumeral joint capsule after the laser-assisted capsular shift

procedure for glenohumeral instability. Am J Sports Med 1999 27: 162-167. [PubMed]

41. Cetik O, Cift H, Comert B, Cirpar M. Risk of osteonecrosis of the femoral condyle after arthroscopic chondroplasty using radiofrequency: A prospective clinical series. Knee Surg Sports Traumatol Arthros 2009 17:24-29. [PubMed]
42. Encalada I, Richmond JC. Osteonecrosis after arthroscopic meniscectomy using radiofrequency. Arthroscopy 2004 20: 632-636. [PubMed]
43. Boykin Jr JV, Molnar JA. Burn scar and skin equivalents. In Wound Healing: *Biochemical and Clinical Aspects*, 523-540, edited by IK Cohen, RF Diegelmann, WJ Lindblad, Philadelphia, WB Saunders, 1992.
44. Sionkowska A. Thermal denaturation of UV-irradiated wet rat tail tendon collagen. Intl J Biological Macromolecules 2005 35:145-149. [PubMed]
45. Good CR, Shindle MK, Griffith MH, Wanich T, Warren RF. Effect of radiofrequency energy on glenohumeral fluid temperature during shoulder arthroscopy. JBJS 2009 91A: 429-434. [PubMed]
46. Schulz MM, Lee TQ, Sandusky MD, Tibone JE, McMahon PJ. The healing effects on the biomechanical properties of joint capsular tissue treated with Ho:YAG laser: an in vivo rabbit study. Arthroscopy 2001 17: 342-347. [PubMed]
47. Aneja A, Karas SG, Weinhold PS, Afshari HM, Dahners LE. Suture plication, thermal shrinkage, and sclerosing agents: effects on rat patellar tendon length and biomechanical strength. Am J Sports Med 2003 33: 1729-1734. [PubMed]
48. Thornton GM, Leask GP, Shrive NG, Frank CB. Ligament scar creep more than normal ligament in early healing. J Orthop Res 2000 18: 238-246. [PubMed]
49. Chen SS, Wright NT, Humphrey JD. Heat-induced changes in the mechanics of a collagenous tissue: isothermal, isotonic shrinkage. J Biomech Eng 1998 120: 382-388. [PubMed]
50. Levy O, Wilson M, Williams H, Bruguera JA, Dodenhoff R, Sforza G, Copeland S. Thermal capsular shrinkage for shoulder instability: midterm longitudinal outcome study. JBJS 83B: 640-645, 2001. [PubMed]
51. Vangsness Jr CT, Mitchell III W, Nimni M, Erlich M, Saadat V, Schmotzer H. Collagen shortening: an experimental approach to heat. Clin Orthop 1997 337: 267-271. [PubMed]
52. Schaefer MS, Gow RM, Moak JP, Saul JP. Mortality following radiofrequency catheter ablation from the Pediatric Radiofrequency Ablation Registry. Am J Cardiol 2000 86: 639-643. [PubMed]
53. Chen S, Haen PS, Walton J, Murrell GAC. The effects of thermal capsular shrinkage on the outcome of arthroscopic stabilization for primary anterior shoulder instability. Am J Sports Med 2005 33:705-711. [PubMed]
54. Levine WN, Clark AM, D'Alessandro DF, Yamaguchi K. Chondrolysis following arthroscopic thermal capsulorrhaphy to treat shoulder instability: a report of two cases. JBJS 2005 87: 616-621. [PubMed]
55. McFarland EG, Kim TK, Banchasuek P, McCarthy EF. Histologic evaluation of the shoulder capsule in normal shoulders, unstable shoulders, and after failed thermal capsulorrhaphy. Am J Sports Med 2002 30: 636-642. [PubMed]
56. Wong KL, Williams GR. Complications of thermal capsulorrhaphy of the shoulder. JBJS 2001 83A: 151-155. [PubMed]
57. Levine WN, Bigliani LU, Ahmad CS. Thermal capsulorrhaphy. Orthopedics 2004 27: 823-826. [PubMed]