Safety and Effectiveness of TenJet, Percutaneous Tenotomy System, at Debriding Tendinopathic Tissues in a Bovine Collagenase-induced Tendinopathy Model

Andrew Wong MS, Pooja Swami MS, Timothy Reed BS, Daniel Grande, PhD
Feinstein Institute of Medical Research, Northwell Health, New York

Background & Significance

Treatment of patients suffering from chronic tendinopathy or tendinosis presents a vexing challenge to a physician with no clear solutions other than surgery to treat the pathologic degradation of the tendon tissue.[1,2] A microscopic analysis of chronic tendinopathy tissue reveals an increased amount of immature type III collagen fibers (mature type I fibers dominate in healthy tendon tissue); loss of collagen continuity and alignment to facilitate load-bearing; an increase in ground substance (the material between the body's cells); and a random increase of vascularization. The appearance of the tendon shifts from a reflective, "white, glistening and firm" surface to a "dull-appearing, slightly brown and soft" surface (mucoid degeneration).[3–5]

While conservative options of physical therapy and corticosteroid injection are moderately effective during the acute inflammatory phases of tendinopathy,[1] surgical debridement of diseased tendon tissue is often a definitive treatment for patients suffering from chronic tendinopathy.[6,7]

The TenJet system created by HydroCision, Inc., North Billerica, MA, uses high pressure saline jet to debride pathologic tissues during percutaneous tenotomy procedures performed under ultrasound guidance. The TenJet handpiece consists of a needle with two lumens: one that delivers sterile saline at high pressure to the debridement site, and the other that evacuates the same fluid and debrided material. Saline pressures at the injection lumen are controlled by settings on HydroCision's Hydrosurgery console. The high pressures at the tip of the injection lumen combined with the low pressure in the evacuation lumen create a venturi suction effect, allowing the saline and debrided material to be evacuated from the debridement site instantaneously.

This study was designed to determine if the TenJet system is effective at debriding tissues resembling the pathologic state of chronic tendinopathy with a collagenase-induced tendinopathy model. The effect of the TenJet system on tissue representative of a healthy tendon was also determined.

Methods & Materials

Bovine ankle extensor tendons were harvested using sterile methods at a local abattoir. Tendons were sectioned into 3.5 cm long explants and kept in organ culture in media (DMEM/F12 50:50 with 1X antibiotic/antimycotic at 37° C with 5% CO_2) for 4 days to allow for metabolic equilibrium. Before the start of an experiment, explants were tagged with sutures at each end.

Ultrasound images were captured between the two suture heads at every 0.08 mm of the tendon using a VEVO 3100 with an MX550D transducer (Fujifilm Visualsonics, Toronto, Ontario), and a 3D model of the tendon was created from ultrasound slices using Fujifilm Visualsonics' software, Vevo Lab (Fujifilm Visualsonics, Toronto, Ontario).

Tendon explants were injected with either 0.05 ml of 10mg/ml collagenase type I to induce a defect or PBS to serve as a control. Collagenase and PBS were mixed with 10% Trypan Blue to visualize the injection site. A 25G syringe needle located midway through the diameter of the tendon at an approximate 45 degree angle was used to inject the solutions along the length of explant. Explants were then incubated at 37° C with 5% CO_2 for 24 hours.

Following the 24-hour incubation, ultrasound imaging was performed again to quantify the degree of induced tendinopathy. To quantify the degree of tendinopathy within any given tendon, the cumulative volume of the defects was divided by the total volume of the tendon to give a volume fraction.

Tendon explants were clamped down, and debridement was performed on the explants using the TenJet device for 2 minutes at settings 5 through 10 (n=3 for each setting). Ultrasound imaging was performed again to quantify the effect of debridement on the tendon.

All experimental explants were fixed in 10% Zinc Formalin for histological analysis for five days. To be embedded for histology, 2-3 mm thick cross-sectional sections were cut in the mid-length (potentially the most affected) region. Approximately 6-8 micron-thick sections of each sample were cut using the microtome, stained with

Hematoxylin and Eosin and imaged using an Olympus BH-2 light microscope mounted with an Olympus DP72 digital microscope camera (Olympus, Center Valley, PA).

Results & Discussion

The tendinopathy model induced by collagenase injection was evaluated using B mode ultrasound. The degree of tendinopathy was graded by the increase in volume fraction of the hypoechoic areas deemed tendinopathic over the total volume of the tendon imaged. There was a statistically significant increase in the volume fraction of the defect when collagenase is injected. Furthermore, volume fraction of the defect is dependent on collagenase dosage; volume fraction increases with increasing collagenase concentration injections. Histology confirmed that these explants could be classified tendinopathic because the collagenase-injected samples showed distinct regions of disorganized collagen and ECM (Figure 2D). This implies that injection of collagenase I is a reliable method for inducing tendinopathy in organ culture.

## The effect of debridement using the Tenjet handpiece on defect volume fraction

Debridement using the TenJet handpiece significantly decreased the defect volume fraction in collagenase-injected explants. Average volume fractions of defects decreased with statistical significance ($p<0.05$) by approximately tenfold ($8.7\pm5.7\%$ pre-debridement, $0.80\pm0.84\%$ Post-debridement). Therefore, application of TenJet on tendons treated with collagenase does debride the majority of tissue exhibiting signs of tendinopathy (Figure 1A).

Debridement using the TenJet handpiece on PBS-treated control explants yielded a statistically significant increase in measured defect volume fraction ($p<0.05$; $0.056\pm0.22\%$ pre-debridement, $0.29\pm0.36\%$ post- debridement). This implies that the application of TenJet resulted in minimal tissue disruption although this is exceedingly small in comparison to the total tendon volume and tendinopathy defects in the collagenase treated groups.

To determine if there was a statistically significant difference in debridement capability between power settings on the SpineJet console when using the TenJet handpiece, a one way ANOVA was conducted between volume fractions of both collagenase-injected samples (Figure 1A) and PBS-injected samples (Figure 1B) with respect to increasing power settings. In both the collagenase-injected and the PBS-injected studies, there was no statistically significant difference when settings were varied ($p=0.84$ for collagenase-injected studies, $p=0.58$ for PBS-injected studies).
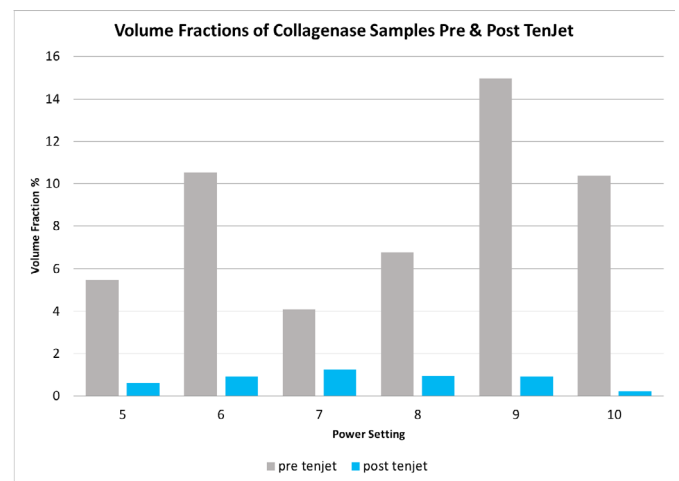

Figure 1A: Bar graph showing means and standard deviations of defect volume fractions in collagenase-injected samples after debridement on power settings 5 through 10. No statistically significant difference in volume fraction was observed by varying the power settings.
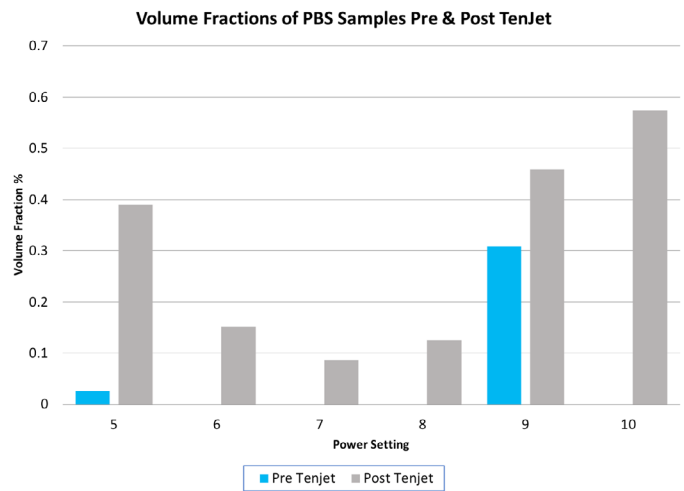

Figure 1B: Bar graph showing means and standard deviations of defect volume fractions in PBS-injected samples after debridement on power settings 5 through 10. No statistically significant difference in volume fraction was observed by varying power settings. Note that the percentage of tissue disruption was minimal.

Histology

Histological analysis (Figure 2) pre-debridement on 10mg/ml collagenase showed a distinct defect characterized by disorganized collagen fibers and more ground matrix. Post-debridement, the complete portion of tendinopathic tendon tissue was absent. This indicates that the application of the TenJet device was able to debride a significant amount, essentially 100% of the disorganized tissue at the defect site. The histology findings show normal tissue present at the defect interface, indicating that all of the disrupted collagenase-induced tissue was completely removed and normal tissue was left intact
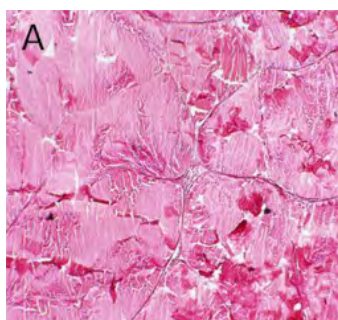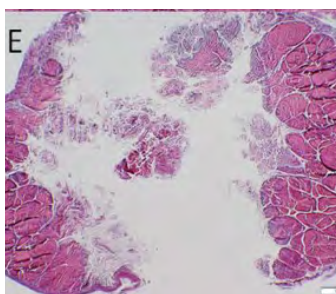
**Figure 2A:** Representative images of PBS-injected control (10x)
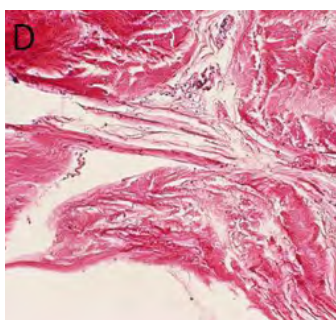
Figure 2D: Collagenase injected tendon tissue (10x). Collagen fibers are disorganized and more loosely bundled than healthy tissue characteristic of tendinopathy.
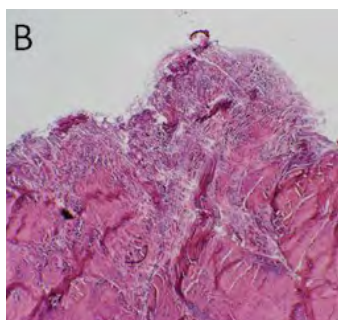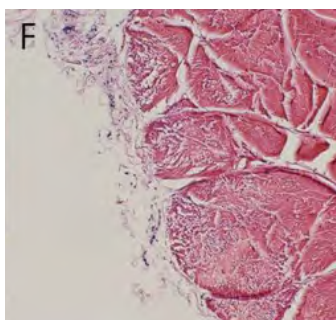

Figure 2B: PBS-injected control treated with the TenJet (2x)

Figure 2E: Collagenase-injected explants treated with the TenJet (2x). Application of the TenJet successfully debrides the majority of the tendinopathic tissue.
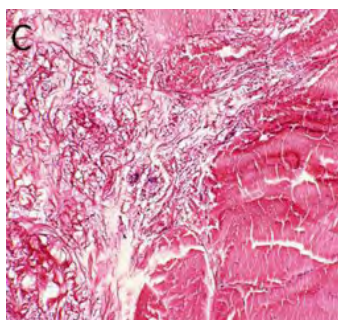
Figure 2C: PBS-injected control treated with the TenJet (10x)

Figure 2F: Collagenase-injected explants treated with the TenJet (2x). Application of the TenJet successfully debrides the majority of the tendinopathic tissue.

References

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Conclusions

The findings obtained in this study clearly demonstrated the TenJet device was effective in removing degenerative tendon tissue in an organ culture model. While, there are several limitations to the ex-vivo tendinopathy model, debridement using the TenJet device confirmed histology findings showing normal tissue present at the defect interface indicating that all of the disrupted collagenase induced tissue was completely removed and normal tissue was left intact. This was a consistent finding throughout the range of instrument settings.