The Utility of Electrocautery for Suture Passage Through Bone: A Biomechanical Study

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Received 7 October 2019; accepted 12 November 2019

DOI 10.1002/jor.24533

ABSTRACT: Electrosurgical devices are routinely employed during surgery. The use of a Bovie Electrosurgical Unit (ESU) to facilitate the passage of a suture needle through bone has not been studied in the literature. This study aimed to identify force reduction with the application of Bovie ESU to the suture needle through the bone. Peak and the average axial force required for a suture needle to penetrate cadaveric proximal humeri were measured using a custom setup. Twenty-four trials were conducted without electricity, and 72 trials were conducted with a Bovie ESU applying current. Needle size and Bovie ESU power settings were varied. t Tests and analysis of variance were used with $p \leq 0.05$ denoting statistical significance. The application of electricity reduced the peak and average axial force needed for a needle to pierce bone, regardless of the Bovie ESU power setting ($p < 0.001$). The average peak force with the Bovie ESU was 65.7 N, compared with 126.0 N without ($p < 0.001$), a 47.9% reduction. The average axial force with the Bovie ESU was 38.2 N compared with 81.8 N without ($p < 0.001$), a 53.3% reduction. There was no significant difference in peak or average axial forces between power settings. At 30 and 90 W of power, larger needle size was associated with significantly lower peak ($p = 0.001$ and $p < 0.001$, respectively) and axial ($p = 0.002$ and $p = 0.004$, respectively) force. The Bovie ESU reduces the axial force required to pass a suture needle through bone. The use of this technique may allow for the avoidance of drilling for soft tissue repair. © 2019 Orthopaedic Research Society. Published by Wiley Periodicals, Inc. J Orthop Res 38:954–960, 2020

Keywords: biomechanics; bone; surgical repair

Soft tissues are routinely approximated to bone in surgical procedures, especially orthopedics. Secure placement of tendons and ligaments next to prepared bone facilitates healing and reduces the risk of rerupture, while also permitting early rehabilitation.[1] There are numerous challenges for surgeons seeking to restore a site's dynamic mechanical properties, and successful attachment of soft tissue structures to bone is therefore accomplished through a variety of established surgical techniques. To keep tissue approximated to bone, holes are frequently placed into bone through which suture, wire, screws, or suture anchors are passed or placed. Bone preparation is typically performed with power drills, tunneling devices, or awls.[2–5] A novel surgical technique in orthopedics involves the use of electrosurgery to facilitate passage of a suture needle through bone without the aid of a drill hole.* Theoretical benefits of this technique may include (i) less time spent for tunneling and suturing activities; (ii) use of less surgical equipment; (iii) creation of smaller bone conduits; and (iv) reduced potential for bone injury.

The Bovie Electrosurgical Unit (ESU) device (Clearwater, FL), hereafter referred to as the "Bovie," uses an alternating current to induce temperature increases within tissue, heating the tissue from the inside out. Heating occurs by two main mechanisms—current-induced friction among ions in the cell cytoplasm, and resistive heating.[6] When placed in immediate proximity with the handheld Bovie instrument tip, the tissue itself becomes the path of least resistance, which results in cutting and/or coagulation, depending upon the current-density settings.[7]

Although Bovie devices have traditionally been used for soft tissue applications, bone can also be theoretically impacted by the apparatus. To date, no studies have assessed or described the use of a Bovie to facilitate the passage of a suture needle through bone. The primary aim of this study was to quantify Bovie-assisted needle penetration of cadaveric bone, and to compare the penetrating properties of Bovie-charged needles to those which are uncharged. The secondary aims were to describe the relationship between Bovie power setting and force required for penetration, as well as the effect of needle size on this relationship.

MATERIALS AND METHODS

A custom apparatus was designed to quantify the effectiveness of Bovie-assisted needle penetration into fresh-frozen cadaveric proximal humeri (Figs. 1 and 2). The force required to penetrate the bone was measured using this apparatus. A MTS Minibionix 858 machine (Eden Prairie, MN) was used to achieve constant linear motion and record accurate force measurements.

Two fresh-frozen cadaveric humeri were dissected to reveal the humeral head and proximal neck of the humerus. Two specimens were necessary in order to provide adequate surface area to complete all trials without piercing the same location more than once. A grounding pad was placed on the skin of the undissected portion of the distal humerus to provide a closed loop for the electric current analogous to use during surgery. The force transducer was electrically isolated by the nylon rod and mount, and penetration force was

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*A resident brought this technique back with him to our institution.

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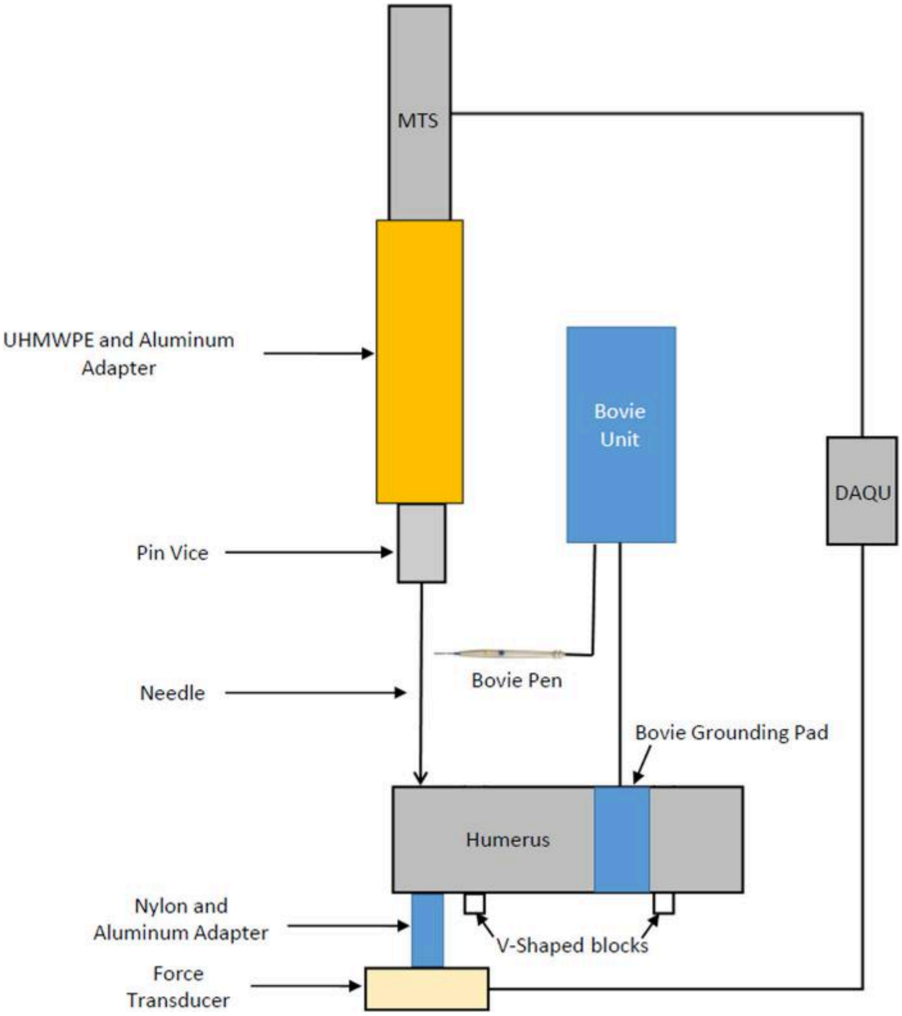

Figure 1. Schematic of testing apparatus. DAQU, data acquisition unit. [Color figure can be viewed at wileyonlinelibrary.com]

recorded every one-hundredth of a second over the course of each trial. Electrical power was applied to the needle using the Bovie System 5000 (Utica, NY). Independent variables analyzed included Bovie power setting and needle size. The pure cut function of the Bovie was used, with power settings of 0 (No Bovie), 30, 60, and 90 W. Needle sizes of #5 suture (KAC-25, metric size 7) and #2 suture (KHC-5 ½ Circle-K Point, metric size 5) were used.

All trials were conducted at a needle loading rate of 1 mm/s. Depth of needle penetration was set to 12 mm, a depth sufficient to penetrate the cortex and enter the humeral canal. The tip of the Bovie pen was used to directly apply current to the needle throughout the duration of each trial.

All trials of penetration were performed through the humeral head. The humeral head was selected to replicate the clinical situation of repairing the subscapularis to the lesser tuberosity through several bone tunnels through the area of the bicipital groove of the humerus. Several trials were initially conducted with axial force applied within this region to best approximate the true surgical approach. However, measured force both with and without the Bovie was noted to be vastly inconsistent as cortical bone density fluctuated along the bicipital groove. To provide an area of relatively uniform density, testing was restricted only to the humeral head.

A post-hoc power analysis determined that for a significance level of 0.05, a sample size of two trials per Bovie setting would be needed to detect a 30% difference in peak force between 0, 30, and 90 W with 80% power; three with 90% power. The 30% difference is a conservative estimation based on clinical experience. For average axial force, three and four trials per power setting would be needed for 80% and 90% power, respectively. Given that these were the minimum numbers required to detect the desired effect sizes and no added resources were needed for additional trials, 12 trials were conducted with each needle size at each Bovie setting, totaling 96, to further increase validity of the results. The peak and average axial force of each trial was determined using Microsoft Excel. Arithmetical means of trials were calculated, and metrics were analyzed using Student's t test and analysis of variance with $p \leq 0.05$ denoting statistical significance.

RESULTS

Peak Force

Average peak and axial forces for bone penetration were reduced among all 72 trials conducted with the Bovie in comparison with the 24 trials conducted without, regardless of Bovie power setting. Table 1 shows comparisons of average peak forces during bone penetration with and without use of the Bovie for both size #5 and #2 needles. Average peak force was

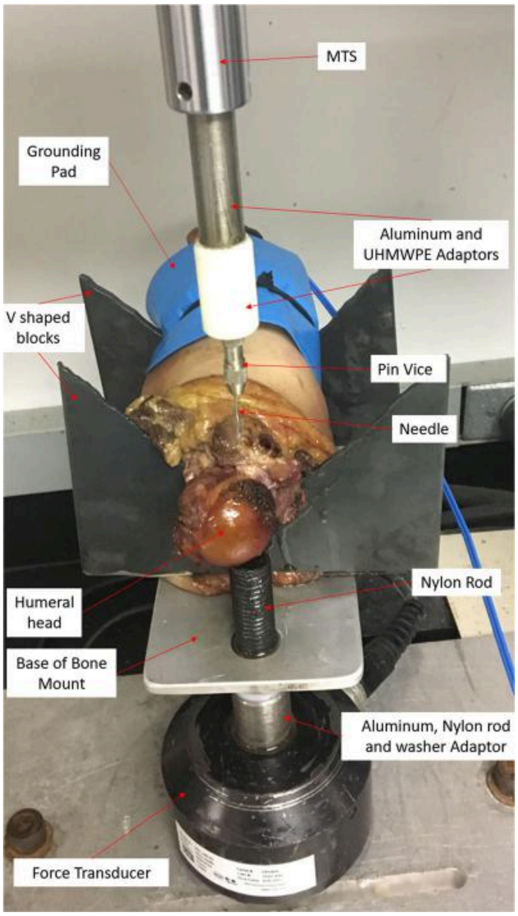

Figure 2. Custom testing apparatus with cadaveric humerus in place. Upon initiation of each trial, the MTS applied axial force downward, forcing the needle through the head of the humerus at a constant speed. Force of penetration was transmitted to the Data Acquisition Unit every one-hundredth of a second. UHMWPE, ultra-high-molecular-weight-polyethylene. [Color figure can be viewed at wileyonlinelibrary.com]

significantly lower with the Bovie than without, regardless of whether the size #5 (58.8 N, $p < 0.001$) or size #2 needle (72.6 N, $p < 0.001$) was used.

Axial Force

Comparison of average axial force is displayed in Table 2. Average force was again significantly lower with use of the Bovie for both the #5 needle ($p < 0.001$) and the #2 needle ($p < 0.001$), with associated average force reductions of 60.9% (54.8 N) and 44.0% (32.5 N), respectively. Collectively, average axial force across all trials regardless of needle size was significantly lower with the Bovie ($p < 0.001$), yielding a reduction of 53.3%. A graphic example of the difference in axial forces required to penetrate bone with and without Bovie use is found in Figure 3.

Power-Force Relationship

When evaluating peak force as a function of Bovie power setting, significant differences were evident for both the #5 needle ($p < 0.001$) and the #2 needle ($p = 0.001$) (Table 3). There was no statistically significant difference in average peak force between any two Bovie power settings. However, differences were significant between peak force without application of the Bovie (0 W) and peak force with application of any of the three assessed Bovie power settings, regardless of needle size (Figs. 4 and 5). Interestingly, no consistent trend was observed across power settings. Average percent force reduction was greatest at 90 W (62.8%) and least at 60 W (48.8%) with use of a size #5 needle, while it was greatest at 60 W (42.5%) and least at 30 W (27.0%) with use of a size #2 needle.

Similar results were observed when assessing the power- axial force relationship (Table 4). Of note, a statistically significant difference in average axial force was found between trials with the Bovie at 30 W (49.4 N) and 60 W (34.9 N) with use of the #2 size needle ($p < 0.001$). No other two Bovie power settings were associated with a significant force difference. As with peak force, average axial force was significantly decreased with use of any of the three Bovie power settings in comparison to force without the Bovie.

Needle Size and Force Relationship

Comparison of average peak and axial forces between the size #5 and size #2 needle at each Bovie power setting are shown in Table 5 and Figure 6. The #5 needle demonstrated significantly lower peak force at 30 W ($p = 0.001$) and 90 W ($p < 0.001$), with corresponding percent force reductions from 0 W of 59.6% and 62.8%, respectively. Differences in peak force were not significantly different at baseline or with use of the Bovie at 60 W. Average axial force was also significantly lower at 30 W ($p = 0.002$) and 90 W ($p = 0.004$) of power with use of the #5 size needle compared with the #2 size needle. Again, differences in force with 0 and 60 W of power were not statistically significant.

DISCUSSION

The use of a Bovie to facilitate the passage of a suture needle through bone offers a potential alternative to

Table 1. Comparison of Average Peak Force (N) With and Without Bovie

Needle Size	No Bovie	Bovie[a]	Percent Force Reduction With Bovie[a]	p-Value
#5	137.0 (±49.3)	58.8 (±15.6)	57.1%	<0.001
#2	115.0 (±37.6)	72.6 (±23.2)	36.9%	<0.001
All[b]	126.0 (±44.3)	65.7 (±20.8)	47.9%	<0.001

Measurements are expressed in Newtons (N) unless otherwise specified.
[a] Average of all trials with Bovie at 30, 60, and 90.
[b] #5 and #2 gauge needle measurements combined.

Table 2. Comparison of Average Axial Force (N) With and Without Bovie

Needle Size	No Bovie	Bovie[a]	Percent Force reduction with Bovie[a]	*p*-Value
#5	89.9 (±35.3)	35.1 (±11.6)	60.9%	<0.001
#2	73.7 (±23.0)	41.2 (±13.5)	44.0%	<0.001
All[b]	81.8 (±30.3)	38.2 (±12.9)	53.3%	<0.001

Measurements are expressed in Newtons (N) unless otherwise specified.
[a] Average of all trials with Bovie at 30 , 60 , and 90 W.
[b] #5 and #2 gauge needle measurements combined.

intraosseous drilling. Findings from this cadaveric study support the use of the Bovie as a means to significantly reduce penetrative force. This is the first study in the literature to describe and formally assess the efficacy of a Bovie to facilitate the passage of a suture needle through bone.

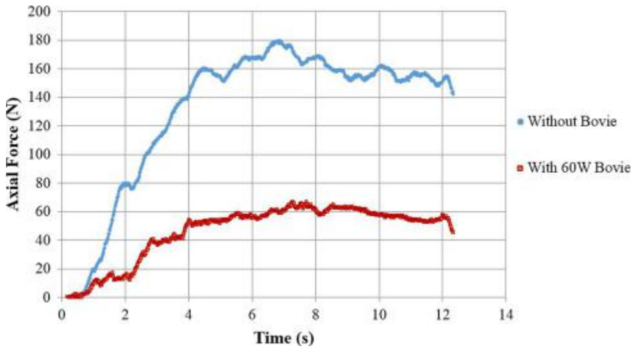

Figure 3. Sample result output for a single trial without Bovie (blue) and a single trial with Bovie (red). Trials depicted for size #5 needle and 60 W Bovie power setting. [Color figure can be viewed at wileyonlinelibrary.com]

Use of the Bovie at any power setting resulted in significantly reduced average peak and average axial penetrative forces compared with forces without the Bovie. These findings support anecdotal clinical experience and the associated hypothesis that electricity facilitates the passage of a needle through bone. The scientific basis of this hypothesis relies on the conversion of electrical energy to heat, and the local heat-mediated destruction of cell walls and intercellular connections near the needle tip with high current density.[6] Disruption of the tissue structure lowers the bone's puncture resistance, reducing the amount of force required for needle passage. Application of the Bovie to facilitate suture needle passage through bone has been used at our institution since this technique was brought to our attention in 2014 by Boileau and Etier.

Although use of the Bovie at any power setting did significantly reduce both peak and axial force during bone penetration, specific trends were not observed with respect to reduction in force as a function of Bovie power setting. We postulate that there may be a threshold current above which no additional benefit to force reduction is achieved. This is consistent with the electrosurgical device's theoretical mechanism of action, in which cell wall destruction is eventually achieved by the needle and no additional benefit is conferred after total vaporization.[8]

Needle size also appears to impact penetrative force when electrical current is applied. Average peak and axial penetrative forces were significantly lower with use of the larger gauge, size #5 suture needle compared with the smaller size #2 needle. Resistance to current is inversely related to cross-sectional area, allowing increased current flow through a larger needle to be concentrated at the needle tip. Theoretically, this increase in concentrated power at the needle-bone interface would also increase the effectiveness of tissue penetration. These results suggest that use of larger-gauge needles may optimize the efficacy of this novel technique.

The effectiveness of the Bovie to reduce penetrative force through bone at any power setting as low as 30 W deviates from existing general laparoscopic literature pertaining to soft tissue, which recommends the cut function of a Bovie to be between 50 and 80 W, with coagulation being optimized between 30 and 50 W.[9] The main contributing factor is likely the smaller area of contact between a needle and tissue compared with that with a traditional cutting tool, which generates an increased concentration of current density. It may also be attributable to automatic voltage adjustments by the Bovie to correct for detected current impedance. Bone is characterized by higher impedance relative to soft tissue, and a design feature of many newer Bovie devices, such as the

Table 3. Comparison of Average Peak Force (N ± Standard Deviation) Without Bovie and Across All Bovie Power Settings*

Needle Size	No Bovie	30 W	60 W	90 W	*p*-Value
#5	137.0 ± 49.3	55.3 ± 11.7 (59.6%)	70.1 ± 19.3 (48.8%)	50.9 ± 6.9 (62.8%)	<0.001
#2	115.0 ± 37.6	84.0 ± 23.8 (27.0%)	66.1 ± 28.5 (42.5%)	67.7 ± 10.8 (41.2%)	<0.001
All[a]	126.0 ± 44.3	69.6 ± 23.5 (44.7%)	68.1 ± 23.9 (45.9%)	59.3 ± 12.3 (52.9%)	<0.001

Measurements are expressed in Newtons (N) unless otherwise specified.
*Average percent decrease in force from 0 W ("No Bovie") at each power setting is expressed in parentheses.
[a] #5 and #2 needle measurements combined.

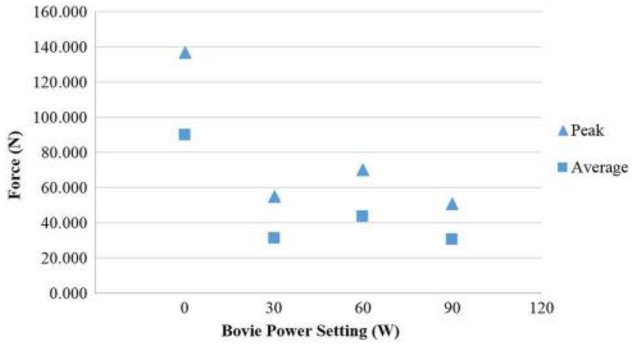

Figure 4. Average peak and axial force measured with size #5 needle for 0 W (no Bovie), 30 W, 60 W, and 90 W Bovie power settings. [Color figure can be viewed at wileyonlinelibrary.com]

one used in the current study, allows the device to sample the impedance of tissue and adjust the voltage accordingly to compensate and maintain effective power.[6,10] Additionally, increased impedance with the same current yields increased resistive heating, allowing for effective cutting at lower power settings in tissues with higher impedance until the maximum voltage for the desired power setting is achieved.[6] No published literature or guidelines exist regarding penetration of bone.

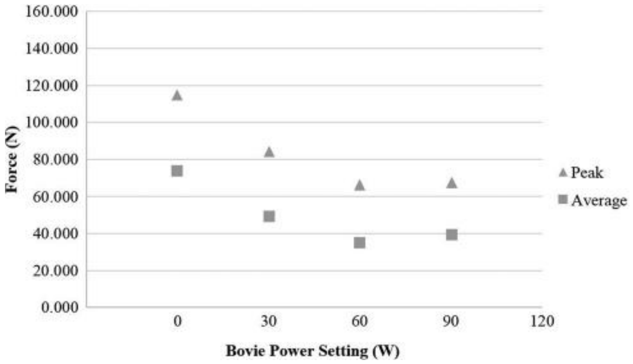

Figure 5. Average peak and axial force measured with size #2 needle for 0 W (no Bovie), 30 W, 60 W, and 90 W Bovie power settings.

Although the Bovie demonstrated effectiveness in facilitating needle passage through the bone at the power setting of 30 W, power was not assessed below this setting. The threshold power required to reduce penetrative force may, therefore, be even lower than 30 W. This is of particular clinical significance, as guidelines for electrosurgery state that the lowest possible power setting should be used to reduce the risk of capacitive coupling and arcing, which can cause burns.[11–13] The power range of 30–90 W used for the current study was determined to be an adequate range for analysis based off of previous literature, which cited optimal cut function power settings for soft tissue to be between 50 and 80 W.[9] Whether application of the Bovie significantly reduces the required force for penetration at power settings below 30 W is worth investigating to minimize the risk of iatrogenic injury; more research is needed to determine the lowest power setting necessary to facilitate the passage of the needle through bone.

We routinely use this technique to pass sutures through the bicipital groove during reattachment of the subscapularis in shoulder arthroplasty. Since adopting this technique in 2014, we no longer utilize routine drilling. A similar approach is used at our institution when repairing the external rotators in the setting of hip arthroplasty. Some key pearls with this technique include the need to prevent the needle and needle driver from touching surrounding soft tissues, which dissipates the energy, making needle passage difficult and increases the likelihood of burning surrounding tissues. Another strategy in preventing dissipation of the applied current is to keep the local area dry as possible.

This study has several limitations. First, cadaveric bone may not mirror the properties of bone in vivo during surgery. However, force measurements on tissue in vivo would not be feasible, and cadaveric studies are frequently utilized to establish biomechanical principles of various surgical techniques. Second, our study used straight needles, creating perpendicular trajectories to the cortical bone. This differs from common surgical practice, which often utilizes curved needles on angled trajectories. However, the MTS machine is engineered to apply a perpendicular axial force and is not equipped to make the minor adjustments in trajectory angle which would be required to pass a curved needle through bone. Therefore, our setup allowed for more reliable and consistent measurements of force. Utilization of more than one cadaveric specimen may have also impacted results, as cortical density varies among individuals. Nonetheless, due to surface area limitations, more than one specimen was necessary in order to carry out multiple trials without repeatedly puncturing the same site on the humeral head. It should also be noted that the only significant difference in force noted between any two Bovie

Table 4. Comparison of Average Axial Force (±Standard Deviation) Without Bovie and Across All Bovie Power Settings*

Needle Size	No Bovie	30 W	60 W	90 W	*p*-Value
#5	89.9 ± 35.3	31.1 ± 7.6 (65.4%)	43.6 ± 13.7 (51.5%)	30.7 ± 8.2 (65.9%)	<0.001
#2	73.7 ± 23.0	49.4 ± 16.8 (33.0%)	34.9 ± 12.6 (52.7%)	39.5 ± 4.8 (46.5%)	<0.001
All	81.8 ± 30.3	40.3 ± 15.8 (50.8%)	39.2 ± 13.6 (52.1%)	35.1 ± 8.0 (57.1%)	<0.001

Measurements are expressed in Newtons (N) unless otherwise specified.
*Average percent decrease in force from 0 W ("No Bovie") at each power setting is expressed in parentheses.

Table 5. Comparison of Average Peak and Axial Force Measurements Between Needle Sizes at Bovie Power Settings of 0, 30, 60, and 90 W*

Bovie Power Setting	#5 Needle	#2 Needle	*p*-Value
Average peak force (±S.D.)			
0 W	137.0 ± 49.3	115.0 ± 37.6	0.233
30 W	55.3 ± 11.7 (59.6%)	84.0 ± 23.8 (27.0%)	0.001
60 W	70.1 ± 19.3 (48.8%)	66.1 ± 28.5 (42.5%)	0.692
90 W	50.9 ± 6.9 (62.8%)	67.7 ± 10.8 (41.2%)	<0.001
Average axial force (±S.D.)			
0 W	89.9 ± 35.3	73.7 ± 23.0	0.196
30 W	31.1 ± 7.6 (65.4%)	49.4 ± 16.8 (33.0%)	0.002
60 W	43.6 ± 13.7 (51.5%)	34.9 ± 12.6 (52.7%)	0.118
90 W	30.7 ± 8.2 (65.9%)	39.5 ± 4.8 (46.5%)	0.004

Measurements are expressed in Newtons (N) unless otherwise specified.
S.D., standard deviation.
*Corresponding percent reductions in force from 0 W are shown in parentheses.

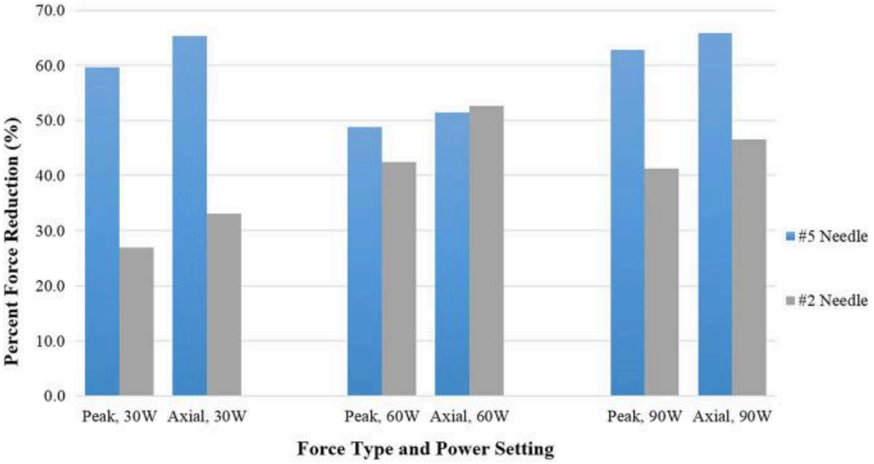

Figure 6. Comparison of percent force reduction from 0 W by Bovie power setting between size #5 and size #2 needle. [Color figure can be viewed at wileyonlinelibrary.com]

power settings were with the size 2 needle, between 30 and 60 W settings. We hypothesize that the 60 W trials with the size 2 needle encountered less dense bone. Although care was taken to keep all trials in close proximity on the humeral head to avoid variations in bone density, we suggest that future studies alternate the power setting with each trial.

This novel technique has multiple potential benefits including cost savings due to the avoidance of bone drills or suture anchors, reduction in operative time, and reduced local bone and soft tissue disruption during ligament and tendon repair. Further research is needed to fully understand the biomechanics of ESU-assisted bone interventions and its clinical applications.

CONCLUSIONS

Use of the Bovie is an effective method to reduce force needed to penetrate bone with a needle, regardless of power setting or needle size used. Although further studies are warranted to determine the minimum threshold needed to provide significant reduction in force, the results of this study provide evidence that power settings as low as 30 W are sufficient to facilitate needle passage. This presents a technically simplified novel approach for creating bone tunnels which lessens the need for drilling and minimizes necessary resources for soft tissue repair.

AUTHORS' CONTRIBUTION

Z.L.L.: conceptualization, investigation, methodology, resources, writing, original draft, writing—review and editing). E.J.L.: conceptualization, formal analysis, investigation, methodology, writing—original draft. H.M.M.: data curation, formal analysis, investigation, methodology, writing—original draft; writing—review and editing. A.M.M., E.W.B., and B.A.P.: conceptualization, data curation, methodology, project administration, supervision, validation, visualization, writing—review and editing. K.B.: conceptualization, investigation, writing—original draft. G.M.: data curation, formal analysis, software, validation, writing—review and editing. All the above authors have read and approved the final submitted manuscript.

ACKNOWLEDGMENTS

We would like to acknowledge Dr. Pascal Boileau and Dr. Brian Etier for introducing the senior and contributing authors to the technique described in this manuscript.

REFERENCES

1. Rothrauff BB, Tuan RS. 2014. Cellular therapy in bone-tendon interface regeneration. Organogenesis 10:13–28.
2. Petri M, Dratzidis A, Brand S, et al. 2015. Suture anchor repair yields better biomechanical properties than transosseous sutures in ruptured quadriceps tendons. Knee Surg Sports Traumatol Arthrosc 23:1039–1045.
3. Browne JA, Pagnano MW. 2012. Surgical technique: a simple soft-tissue-only repair of the capsule and external rotators in posterior-approach THA. Clin Orthop Relat Res 470:511–515.
4. Harris J, Abrams G, Yanke A, et al. 2014. Suture anchor repair of quadriceps tendon rupture. Orthopedics 37:183–186.
5. Cho C-H, Song K-S, Min B-W, et al. 2012. Anterolateral approach for mini-open rotator cuff repair. Int Orthop 36:95–100.
6. Munro MG. 2012. Fundamentals of electrosurgery part I: principles of radiofrequency energy for surgery. In: Feldman L, Fuchshuber P, Jones DB, editors. *The SAGES Manual on the Fundamental Use of Surgical Energy (FUSE)*. New York, NY: Springer. https://doi.org/10.1007/978-1-4614-2074-3_2
7. Ferreira H, Ferreira C. 2015. Principle and use of electrosurgery in Laparoscopy. JSLS J Soc Laparoendosc Surg 69–77. https://doi.org/10.5005/jp/books/12446_6
8. Bovie Medical Corporation. 2016. Understanding Electrosurgery. Clearwater, FL: Bovie Medical Corporation. http://www.boviemedical.com/downloads/UnderstandingElectrosurgeryLit_r3.pdf
9. Alkatout I, Schollmeyer T, Hawaldar NA, et al. 2012. Principles and safety measures of electrosurgery in laparoscopy. JSLS J Soc Laparoendosc Surg 16:130–139.
10. CONMED. 2016. System 5000 Electrosurgical Unit (ESU) Brochure. https://www.conmed.com/-/media/conmed/documents/literature/mcm2016200system5000brochure_lr.ashx
11. F Mattucci K, J Militana C. 2003. The prevention of fire during oropharyngeal electrosurgery. Ear Nose Throat J 82:107–109.
12. AST Standards of Practice for Use of Electrosurgery. 2012. http://www.ast.org/uploadedFiles/Main_Site/Content/About_Us/Standard Electrosurgery.pdf
13. Smith TL, Smith JM. 2001. Electrosurgery in otolaryngology–head and neck surgery: principles, advances, and complications. Laryngoscope 111:769–780.