Osseous Vascularity of the Medial Elbow After Ulnar Collateral Ligament Reconstruction

A Comparison of the Docking and Modified Jobe Techniques

Christopher L. Camp,*[†‡] MD, Craig E. Klinger,[§] BA, Lionel E. Lazaro,[†] MD, Jordan C. Villa,[§] MD, Jelle P. van der List,[†] MD, David W. Altchek,[†] MD, Dean G. Lorich,[§] MD, and Joshua S. Dines,[†] MD
Investigation performed at the Hospital for Special Surgery, New York, New York, USA

Background: Although vascularity plays a critical role in healing after ulnar collateral ligament (UCL) reconstruction, intraosseous blood flow to the medial epicondyle (ME) and sublime tubercle remains undefined.

Purpose: To quantify vascular disruption caused by tunnel drilling with the modified Jobe and docking techniques for UCL reconstruction.

Study Design: Controlled laboratory study.

Methods: Eight matched pairs (16 specimens) of fresh-frozen cadaveric upper extremities were randomized to 1 of 2 study groups: docking technique or modified Jobe technique. One elbow in each pair underwent tunnel drilling by the assigned technique, while the contralateral elbow served as a control. Pregadolinium and postgadolinium magnetic resonance imaging were performed to quantify intraosseous vascularity within the ME, trochlea, and proximal ulna. Three-dimensional computed tomography (CT) and gross dissection were performed to assess terminal vessel integrity.

Results: Ulnar tunnel drilling had minimal impact on vascularity of the proximal ulna, with maintenance of >95% blood flow for each technique. Perfusion in the ME was reduced 14% (to 86% of baseline) for the docking technique and 60% (to 40% of baseline) for the modified Jobe technique (mean difference, 46%; $P = .029$). Three-dimensional CT and gross dissection revealed increased disruption of small perforating vessels of the posterior aspect of the ME for the modified Jobe technique.

Conclusion: Although tunnel drilling in the sublime tubercle appears to have a minimal effect on intraosseous vascularity of the proximal ulna, both the docking and modified Jobe techniques reduce flow in the ME. This reduction was 4 times greater for the modified Jobe technique, and these findings have important implications for UCL reconstruction surgery.

Clinical Relevance: As the rate of revision UCL reconstructions continues to rise, investigation into causes for failure of primary surgery is needed. One potential cause is poor tendon-to-bone healing due to inadequate vascularity. This study quantifies the amount of vascular insult that is incurred in the ME during UCL reconstruction. While vascular insult is only one of many factors that affects the surgical success rate, surgeons performing this procedure should be mindful of this potential for vascular disruption.

Keywords: medial epicondyle; vascularity; ulnar collateral ligament reconstruction; Tommy John; docking technique; modified Jobe technique

In recent years, the number of ulnar collateral ligament (UCL) reconstructions (commonly referred to as "Tommy John surgery") performed has been rising rapidly.[7,8,13,16] Although these patients generally experience high rates of return to throwing (80%-90%),[3,11,12,29,32] not all players return to full competition, and some require revision surgery.[6,10,18,24] Recent reports have demonstrated rising rates of revision surgery that are outpacing the growth of primary UCL reconstruction procedures.[18,24] Although failure of primary surgery is multifactorial, potential reasons for failure include poor healing of the tendon graft to bone, osseous fractures, tunnel malpositioning, or inappropriately paced return-to-throw programs.[10,18,26,41] In an attempt to maximize functional outcomes and mitigate the risk for revision surgery, a number of different UCL reconstruction techniques have been developed.[1,4,9,32] Of these, the most commonly used are the modified Jobe technique[1,2] and the docking technique.[4,32]

The first descriptions of the modified Jobe technique were initially published in 2000 and 2001[2,36] as an update

to the original description of UCL reconstruction published in 1986 by Jobe et al.[17] Benefits of the modified Jobe technique included preservation of the flexor pronator mass and subcutaneous ulnar nerve transposition (compared with submuscular transposition). This was further modified to the docking technique, which was initially published in 2002.[32] Purported benefits of the docking technique included decreased bone removal, flexor-pronator preservation, avoidance of routine ulnar nerve transposition, and robust graft tensioning.[4] Although complications have been reported to occur in 6% (docking technique) and 19% (modified Jobe technique) of cases, a large proportion of these are neurological in nature.[37] Nonneurological complications such as graft failure or medial epicondyle (ME) fractures have been reported in 2% to 6% of primary UCL reconstruction cases.[37]

Although these techniques have been studied in detail in prior biomechanical analyses,[5,25,27,28,30] very little is known about their impact on vascular integrity of the ME of the humerus and the sublime tubercle of the ulna (the areas where drilling and bone removal occur during UCL reconstruction). Because robust vascularity is essential for graft healing within bone tunnels and sockets, a better understanding of the vascular insult incurred during these reconstruction techniques is desired. This is especially true in the distal humerus, where decreased osseous vascularity has demonstrated an increased risk for osteonecrosis, fracture nonunion, and impaired healing.[20,38,39,42] Since an initial detailed description of the arterial anatomy of the elbow in 1997 by Yamaguchi et al,[42] a number of studies have furthered our knowledge of the intraosseous and extraosseous blood supply of the distal humerus[20,38,39,42] and proximal ulna.[14,38,42] The primary blood supply to the ME is the inferior ulnar collateral artery (IUCA) from the brachial artery; however, the ulnar artery also contributes to a lesser extent via branches of the posterior ulnar recurrent artery, which anastomose with the IUCA. Although the vascular flow to the epicondyles is generally considered robust, the central aspect of the distal humerus has been described as a watershed area that is at risk for vascular insult.[20,38,39,42] On the ulnar side, the medial ulna and sublime tubercle are supplied by branches of the ulnar artery, including the ulnar recurrent trunk and the anterior ulnar recurrent artery.[14,38,42]

Recently, the impact of surgical dissection on osseous blood flow has been studied in other anatomic regions such as the patella and femoral neck[19,21,22,33]; however, the vascular insult created during drilling of the medial elbow remains undefined. As the rate of revision UCL reconstructions continues to rise rapidly, it is critical that

a better understanding of this process be obtained. Accordingly, the purposes of this study were to (1) describe the vascular supply to the ME and proximal ulna and (2) quantify and compare the vascular disruption created during tunnel drilling for the modified Jobe technique and docking technique. We hypothesized that both surgical techniques would equally decrease blood flow to the proximal ulna; however, because more bone is removed from the humeral side with the modified Jobe technique, we hypothesized that it would result in a greater decrease in flow to the ME compared with the docking technique.

METHODS

After approval by our institutional review board, 8 pairs (total of 16 specimens) of fresh-frozen cadaveric upper extremities were randomized by a random number generator to 1 of 2 study groups: modified Jobe technique or docking technique (Figure 1). Osseous vascularity was assessed using techniques that have previously been validated for other anatomic regions.[19,22,23,33] All specimens underwent limited dissection to identify the brachial artery proximally and the radial and ulnar arteries distally. Appropriately sized cannulas (DLP; Medtronic) were inserted into the brachial artery 10 cm distal to the greater tuberosity of the humerus and the ulnar artery 8 cm proximal to the distal radius. The radial artery and all remaining identifiable vessels were ligated at these locations. Surgical exposure of the UCL was performed on all specimens. This was completed using an 8-cm incision beginning 2 cm proximal to the ME and extending distally beyond the sublime tubercle with the arm in 30° of flexion. A muscle-splitting approach through the flexor carpi ulnaris was utilized to expose the ligament and capsule.

Dissection and Surgical Procedures

A total of 4 pairs of elbows (8 specimens) were randomized to the docking technique group, while the other 4 pairs (8 specimens) were assigned to the modified Jobe technique group. For both techniques, all tunnels were drilled by a fellowship-trained sports medicine surgeon with extensive experience in UCL reconstruction (J.S.D.). With the docking technique, one of the elbows from each matched pair underwent tunnel drilling using a UCL Reconstruction Instrument Set (Arthrex) to improve accuracy and minimize surgeon variability (Figure 2A). The native UCL was incised in line with its fibers. A 3.5-mm drill was used to create 2 converging ulnar sockets at the sublime tubercle,

*Address correspondence to Christopher L. Camp, MD, Mayo Clinic, 200 First Street Southwest, Rochester, MN 55905, USA (email: camp.christopher@mayo.edu) (Twitter: @ChrisCampMD).

†Sports Medicine and Shoulder Service, Hospital for Special Surgery, New York, New York, USA.

‡Department of Orthopedic Surgery and Sports Medicine, Mayo Clinic, Rochester, Minnesota, USA.

§Orthopedic Trauma Service, Hospital for Special Surgery, New York, New York, USA.
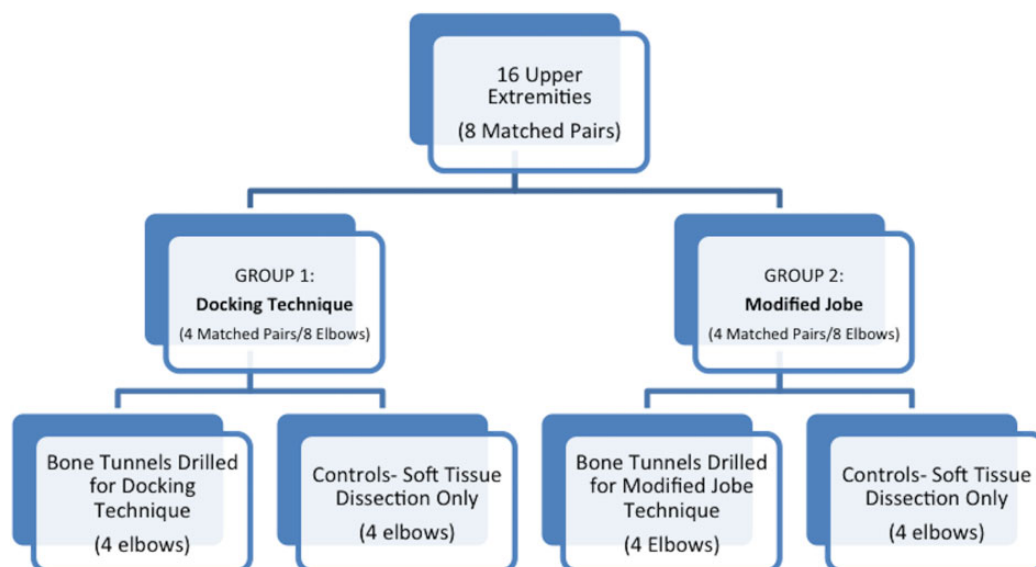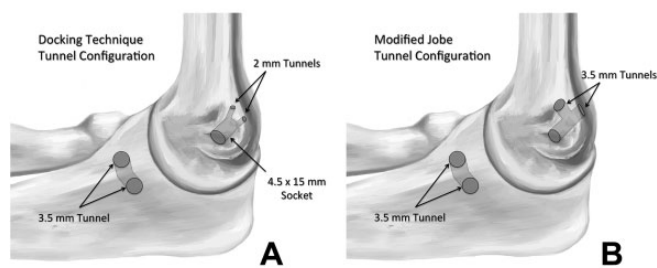
Figure 1. Specimen allocation.

Figure 2. Tunnel size and configuration for the (A) docking and (B) modified Jobe techniques.

while the humeral socket was drilled in the ME with a 4.5-mm drill to a depth of 15 mm. Two small holes (2 mm) were created at the base of this socket using the humeral drill guide. Each of these small holes was created anterior to the intermuscular septum, and a minimal distance (bone bridge) of 10 mm was maintained between the two. The ulnar nerve was protected, but it was not released or transposed. For the control elbows with the docking technique, the same surgical dissection was performed, but the tunnels/sockets were not drilled. Grafts were not passed for any of the elbows.

With the modified Jobe technique, one elbow from each matched pair underwent tunnel drilling, while the accompanying elbow served as the matched control (soft tissue dissection only with no tunnel drilling). For the elbows receiving tunnels, a 3.5-mm drill was used to place 2 converging sockets on either side of the sublime tubercle utilizing the ulnar drilling guide (same technique as for the docking technique). On the humeral side, a 3.5-mm drill was used to create a tunnel in the ME in the center of the humeral footprint of the UCL (Figure 2B). This was continued until it exited the posteromedial cortex of the humerus just proximal to the ME. The humeral drilling guide was

used to create a second 3.5-mm tunnel from the anterior cortex that connected to the previously drilled tunnel. This technique was similar to the original descriptions of the modified Jobe technique,[1,2,36] with the only exception being the utilization of drill guides to improve surgical precision and accuracy. To minimize the risk of additional vascular insult, the ulnar nerve was identified and protected, but it was not dissected or transposed.

Magnetic Resonance Imaging for Perfusion Analysis

After cannulation, dissection, and tunnel drilling (for the 8 elbows receiving tunnels), all specimens underwent a quantitative protocol using 3.0-T magnetic resonance imaging (MRI; General Electric). The quantitative MRI protocol consisted of baseline noncontrast MRI, followed immediately by contrast-enhanced MRI. For all contrast-enhanced scans, gadolinium–diethylenetriamine pentaacetic acid (Gd-DTPA) was diluted using normal saline to a concentration of 3:1 (saline to Gd-DTPA). Ten milliliters of contrast was simultaneously injected into the ulnar and brachial artery cannulas by the same investigator for all study specimens (C.E.K.). Postcontrast MRI was then performed. Because Gd-DTPA detail is optimized on fat-suppressed imaging, this imaging sequence was utilized to perform qualitative and quantitative MRI analyses. Vascular volumetric analysis was completed using customized IDL software (version 6.4; Exelis) on coronal-plane MRI.

On each series of scans, vascularity was assessed for 3 standardized regions of interest (ROIs): ME (medial to humeral tunnels/sockets), trochlea (just lateral to humeral tunnels/sockets), and proximal ulna (between ulnar tunnel and articular surface) (Figure 3). Signal intensity enhancement (change between precontrast and postcontrast MRI) was quantified in each control elbow and subsequently compared with its matched experimental elbow for each of the 3
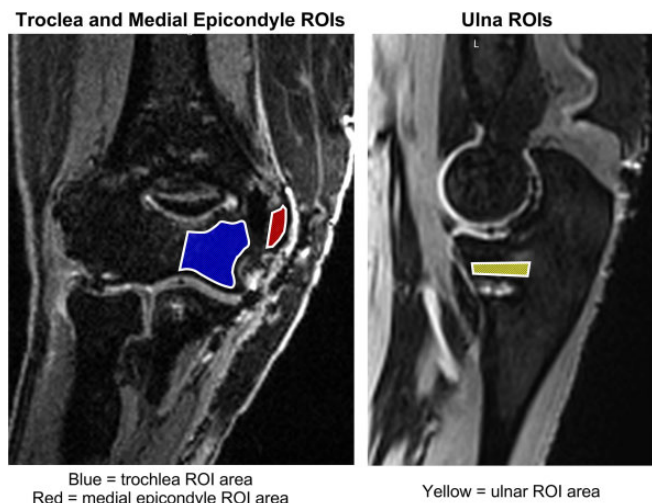
Figure 3. Regions of interest (ROIs) for quantitative vascular analysis. The trochlear ROI (blue shading) was obtained just lateral to the tunnel or socket drilled in the medial epicondyle. The medial epicondylar ROI (red shading) was designated as the area just medial to the tunnel/socket. For the proximal ulnar ROI (yellow shading), the area between the drilled tunnel and articular surface was analyzed.

standardized ROIs . All changes in signal intensity between precontrast and postcontrast images were normalized using nonenhancing muscle tissue as a baseline. The weighted mean signal intensity per voxel was calculated for each ROI on all elbows.

Computed Tomography With 3-Dimensional Reconstruction and Gross Dissection

After MRI, all specimens were injected with 50 mL (25 mL/cannula) of polyurethane compound (PMC-780; Smooth-On) mixed with barium sulfate radiopaque contrast agent (Liquid Polibar Plus 900203; Bracco Diagnostics) at 40% concentration. Two distinct colors of polyurethane were injected into each cannula (purple for the ulnar artery and green for the brachial artery) to better delineate the relative contributions of each. After the solution was allowed to polymerize for 24 hours, all elbows underwent computed tomography (CT) with the acquisition of axial imaging, with sagittal, coronal, and 3-dimensional reconstruction images. This was followed by meticulous gross dissection. During the review of CT scans and gross dissection, special attention was paid to the extraosseous and intraosseous course of each vessel surrounding the ME and sublime tubercle. The location of the perforating terminal vessels was documented to assess the topographic location of each with respect to the perfusion pattern of the ME and sublime tubercle. Photographs were taken for documentation.

Statistical Analysis

Statistical analysis was performed using SPSS version 21 (IBM). Nonparametric Mann-Whitney *U* tests were used to compare the mean difference in MRI perfusion (difference in signal intensity enhancement before and after contrast administration) between controls and experimental elbows for each of the described ROIs. Similar comparisons were made between the mean reduction in perfusion between control and experimental elbows for the docking technique versus modified Jobe technique for each ROI. Results are reported as means with their associated SDs and ranges. For all comparisons, only *P* values <.05 were considered to represent statistical significance.

RESULTS

Quantitative MRI

For elbows undergoing tunnel drilling using the docking technique, a mean of 86% ± 15% (median, 87%; range, 70%-100%) of perfusion was maintained in the ME compared with the matched controls. In this group, 99% ± 1% (median, 100%; range, 98%-100%) was maintained in the trochlea, while 96% ± 5% (median, 98%; range, 89%-100%) of perfusion was maintained in the proximal ulna. For elbows undergoing drilling by the modified Jobe technique, the amount of perfusion maintained was 40% ± 20% (median, 37%; range, 18%-67%) in the ME, 94% ± 13% (median, 100%; range, 74%-100%) in the trochlea, and 99% ± 3% (median, 100%; range, 95%-100%) in the proximal ulna compared with matched controls (Table 1 and Figure 4).

When comparing the maintenance of perfusion between the 2 study groups, the mean percentage of maintained vascularity was 46% higher in the ME for the docking technique as compared with the modified Jobe technique (*P* = .029). The difference of maintained perfusion was minimal between the 2 techniques in the trochlea (mean difference, 6%; *P* = .866) and proximal humerus (mean difference, –2%; *P* = .686) (Table 1).

CT and Gross Dissection

Terminal vessels of the brachial artery were consistently identified in all specimens. All elbows demonstrated traceable continuity of extraosseous vessels into the medullary canal of the ROIs. There were no appreciable differences in observed vascularity surrounding the sublime tubercle across any of the control or experimental groups. In the ME, there was no evidence of terminal IUCA disruption in any of the control elbows (n = 8) or elbows that underwent the docking technique (n = 4); however, 3 of 4 elbows with the modified Jobe technique demonstrated disruption of terminal branches as they entered the anterior and/or posterior surface of the ME (Figures 5 and 6).

DISCUSSION

Contrary to our hypothesis, tunnel drilling had minimal impact on osseous vascularity of the proximal ulna and trochlea; however, both techniques reduced flow to the ME (medial to the site of tunnel drilling), which was consistent with the stated hypothesis. While the docking

TABLE 1
Alterations in Signal Intensity Between Precontrast and Postcontrast Magnetic Resonance Imaging
for Study Elbows Compared With Their Matched Controls[a]

Location	Maintenance of Flow for Study Elbow vs Contralateral Matched Control, Mean ± SD (Range), %		Mean Difference in Maintenance of Flow (Docking – Modified Jobe), %	P
	Docking Technique	Modified Jobe Technique		
Medial epicondyle (medial to tunnels)	86 ± 15 (70-100)	40 ± 20 (18-67)	46	**.029**
Trochlea (lateral to tunnels)	99 ± 1 (98-100)	94 ± 13 (74-100)	6	.886
Ulna (between tunnel and articular surface)	96 ± 5 (89-100)	99 ± 3 (95-100)	−2	.686

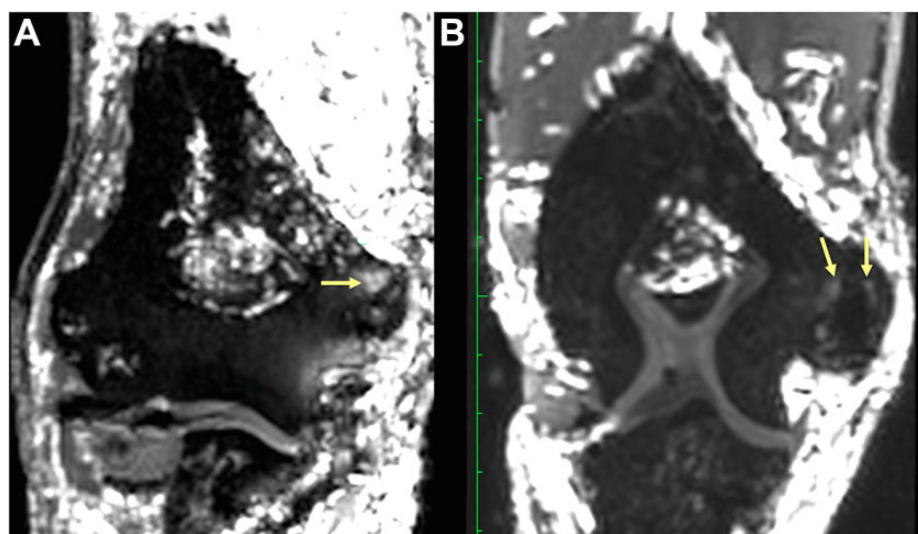[a]Boldfaced value indicates statistical significance ($P < .05$).

Figure 4. Representative postcontrast magnetic resonance imaging, with yellow arrows demonstrating quantifiable perfusion in the medial epicondyle after drilling with the (A) docking technique and (B) modified Jobe technique.

technique maintained 86% of flow in the ME, only 40% of flow was maintained in the ME with the modified Jobe technique ($P = .029$).

Although the docking and modified Jobe techniques are the most commonly utilized methods for reconstructing the UCL, there are very few head-to-head comparisons of the techniques. One study has suggested that the docking technique may be biomechanically superior to the modified Jobe technique[30]; however, the clinical implications of these findings remain uncertain. While it is unknown if one technique leads to higher rates of revision surgery compared with the other, it is well established that the overall rate of revision surgery is on the rise.[18,24] The cause of this increase is multifactorial and likely related to extrinsic factors such as increased throwing velocity, lack of sufficient rest between seasons, and pressure to return to play as early as possible; however, other intrinsic and surgical factors contribute to healing of the bone-to-tendon interface. Some of these potential factors include graft isometry, tension applied at the time of reconstruction, strain on the graft during the early healing phase, graft structural integrity, bone quality, as well as the local vascular, cellular, and immunomodulatory

environment of healing tissue.[15,31,34,35,40] While many of these factors may be out of the control of the patient and surgeon, those that are modifiable should be optimized in an attempt to maximize the potential for robust healing.

It is well established that vascularity is needed for biological healing of tissue, including healing of the tendon-bone interface. Although this study was not able to determine a minimal amount of vascularity that must be maintained for optimal graft healing, it is reasonable to postulate that higher degrees of vascularity would have a beneficial effect on graft incorporation. It is also worth noting that the primary source of vascularity to the graft-bone interface is uncertain. It is likely that both intraosseous flow and extraosseous structures (local perforating vessels) play an important role in this process, but the precise contribution of each remains unknown .

In contrast to the stated hypothesis, vascularity was only minimally disrupted in the proximal ulna after drilling ulnar tunnels. The primary vascular supply to this region, the anterior ulnar recurrent artery, branches off of the ulnar recurrent trunk distal to these tunnels and travels proximally to vascularize the subchondral surface. Although the
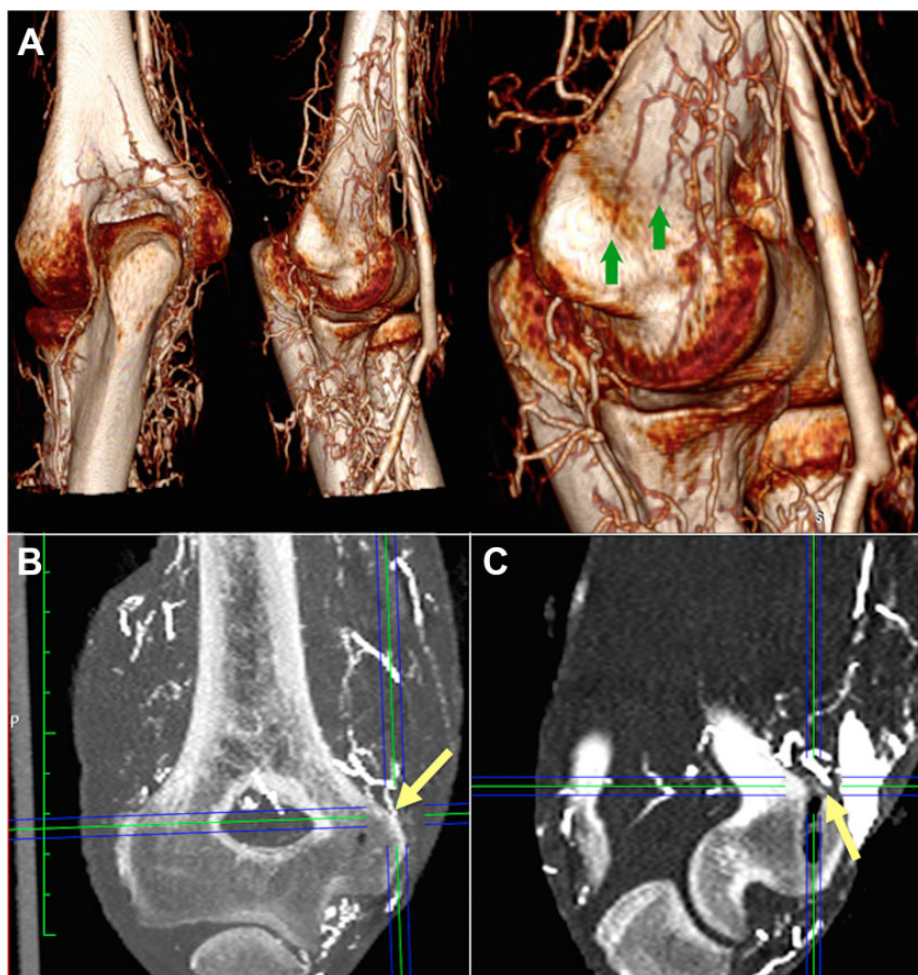
Figure 5. (A) Computed tomography with 3-dimensional reconstruction demonstrating robust vascularity of the elbow. (B, C) On the 2-dimensional images, terminal vessels can be traced into the medial epicondyle (yellow arrows). (B) Note that the postero-lateral cortex remains intact for the elbow that underwent drilling by the docking technique, (C) while the tunnel drilled with the modified Jobe technique violates the posterior cortex and approaches the terminal vessel.

ulnar tunnels likely violated this path, perfusion was well maintained at 96% to 99% of baseline. This maintenance of vascularity is likely because of collateral flow from the posterior ulnar recurrent artery posteriorly and the IUCA proximally. There is a rich network of small vessel contributories in this region of the proximal ulna.[14,38,42]

For the ME, alterations in interosseous flow appear to be more vulnerable to tunnel drilling. Terminal branches of the IUCA supply both the anterior and posterior aspects of the ME, and these structures are at risk during drilling of the ME. Although the docking and modified Jobe techniques both create a total of 3 cortical disruptions in the ME (1 distal and 2 proximal), they differ in their size and locations. While the docking technique allows for a pair of 2-mm holes to be placed proximally in the anterior ME, the modified Jobe technique relies on a pair of larger diameter holes (typically 3.5 mm) placed proximally in the anterior and posterior ME (1 on each side). Although it is difficult to know for certain whether it was the size of the tunnels (3.5 mm) or the location (1 anterior and 1 posterior) that resulted in increased

vascular insult for the modified Jobe technique, both factors may have contributed to this finding. During gross dissection, terminal branches of the IUCA were more commonly violated on the posterior aspect of the ME for the modified Jobe technique, while this area was spared for elbows undergoing the docking technique. The increased diameter of the tunnels also increases the probability that the drill will encounter terminal vessels either at or deep to the cortical surface.

There are a number of limitations to this study that warrant discussion. Namely, this work was performed in cadaveric specimens and relies on "time-zero" data. Therefore, the revascularization process that occurs after tunnel drilling in the clinical population could not be assessed or accounted for. In this study, tendon grafts and fixation devices (sutures, screws, buttons, etc) were not placed, and implantation of these tissues/devices could have an additional impact on vascularity that was not accounted for. Another limitation is the potential for small vessel disruption secondary to dissection and analysis rather than tunnel drilling. Although loupe magnification was utilized and
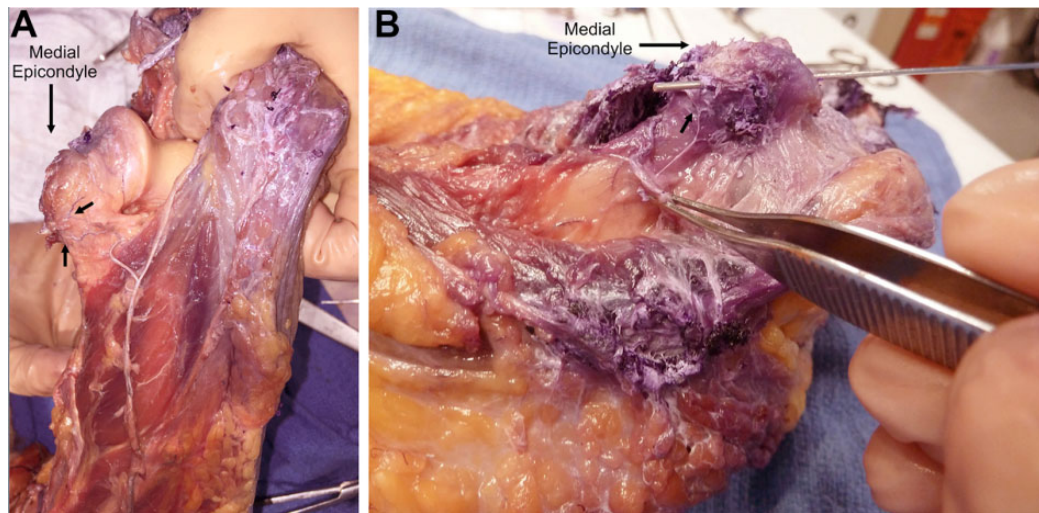
Figure 6. Gross dissection performed after computed tomography. (A) For an elbow that underwent tunnel drilling by the docking technique, the terminal vessels of the inferior ulnar collateral artery (small black arrows) can be identified along the medial epicondyle. (B) In a specimen that underwent drilling by the modified Jobe technique, the trajectory of the tunnel (indicated by the metal probe) approaches the terminal branches (small black arrows) as they reach the medial epicondyle.

meticulous care was taken to minimize unintended damage, this is certainly a possibility. Additionally, some of these specimens may have had pre-existing microvascular disease, variable vessel size at baseline, or increased age that could have affected vascular flow. Accordingly, all experimental elbows were compared with their matched contralateral elbows in an attempt to control for these variables. Ultimately, it remains unknown where the vascular flow comes from after UCL reconstruction, and this work was not able to differentiate intraosseous from extraosseous contributions. Finally, the minimal amount of vascularity required for robust healing remains unknown, and accordingly, the clinical significance of a 14% or 60% reduction cannot be determined from this work.

CONCLUSION

Drilling the ulnar tunnel during UCL reconstruction has minimal impact on vascularity of the proximal ulna. On the humeral side, both the docking technique and modified Jobe technique resulted in decreased vascularity in the ME, and this reduction was 4 times greater for the modified Jobe technique compared with the docking technique (60% vs 14%, respectively; $P = .029$). Although the minimal amount of vascularity required for healing is unknown, care should be taken to avoid terminal branches of the IUCA when drilling tunnels in the ME in an attempt to maximize the healing potential. This is particularly true on the posterior aspect of the ME. Additional study of these implications in the clinical population is warranted.

REFERENCES

1. Andrews JR, Jost PW, Cain EL. The ulnar collateral ligament procedure revisited: the procedure we use. *Sports Health*. 2012;4(5):438-441.

2. Azar FM, Andrews JR, Wilk KE, Groh D. Operative treatment of ulnar collateral ligament injuries of the elbow in athletes. *Am J Sports Med*. 2000;28(1):16-23.

3. Cain EL, Andrews JR, Dugas JR, et al. Outcome of ulnar collateral ligament reconstruction of the elbow in 1281 athletes: results in 743 athletes with minimum 2-year follow-up. *Am J Sports Med*. 2010; 38(12):2426-2434.

4. Camp CL, Dines JS, Voleti PB, James EW, Altchek DW. Ulnar collateral ligament reconstruction of the elbow: the docking technique. *Arthrosc Tech*. 2016;5(3):e519-e523.

5. Chronister JE, Morris RP, Andersen CR, Buford WL, Bennett JM, Mehlhoff TL. A biomechanical comparison of 2 hybrid techniques for elbow ulnar collateral ligament reconstruction. *J Hand Surg Am*. 2014; 39(10):2033-2040.

6. Conte S, Fleisig GS, Dines JS, et al. Prevalence of ulnar collateral ligament surgery in professional baseball players. *Am J Sports Med*. 2015;43(7):1764-1769.

7. Conte SA, Camp CL, Dines JS. Injury trends in Major League Baseball over 18 seasons: 1998-2015. *Am J Orthop*. 2016;45(3):116-123.

8. Degen RM, Camp CL, Bernard JA, Dines DM, Altchek DW, Dines JS. Current trends in ulnar collateral ligament reconstruction surgery among newly trained orthopaedic surgeons. *J Am Acad Orthop Surg*. 2017;25(2):140-149.

9. Dines JS, ElAttrache NS, Conway JE, Smith W, Ahmad CS. Clinical outcomes of the DANE TJ technique to treat ulnar collateral ligament insufficiency of the elbow. *Am J Sports Med*. 2007;35(12): 2039-2044.

10. Dines JS, Yocum LA, Frank JB, ElAttrache NS, Gambardella RA, Jobe FW. Revision surgery for failed elbow medial collateral ligament reconstruction. *Am J Sports Med*. 2008;36(6):1061-1065.

11. Dodson CC, Thomas A, Dines JS, Nho SJ, Williams RJ, Altchek DW. Medial ulnar collateral ligament reconstruction of the elbow in throwing athletes. *Am J Sports Med*. 2006;34(12):1926-1932.

12. Erickson BJ, Chalmers PN, Bush-Joseph CA, Verma NN, Romeo AA. Ulnar collateral ligament reconstruction of the elbow: a systematic review of the literature. *Orthop J Sports Med*. 2015;3(12):2325967115618914.

13. Erickson BJ, Nwachukwu BU, Rosas S, et al. Trends in medial ulnar collateral ligament reconstruction in the United States: a retrospective review of a large private-payer database from 2007 to 2011. *Am J Sports Med*. 2015;43(7):1770-1774.

14. Hardy BT, Glowczewskie F, Wright TW. Vascular anatomy of the proximal ulna. *J Hand Surg Am*. 2011;36(5):808-810.

15. Hettrich CM, Gasinu S, Beamer BS, et al. The effect of mechanical load on tendon-to-bone healing in a rat model. *Am J Sports Med*. 2014;42(5):1233-1241.

16. Hodgins JL, Vitale M, Arons RR, Ahmad CS. Epidemiology of medial ulnar collateral ligament reconstruction: a 10-year study in New York State. *Am J Sports Med*. 2016;44(3):729-734.

17. Jobe FW, Stark H, Lombardo SJ. Reconstruction of the ulnar collateral ligament in athletes. *J Bone Joint Surg Am*. 1986;68(8):1158-1163.

18. Jones KJ, Conte S, Patterson N, ElAttrache NS, Dines JS. Functional outcomes following revision ulnar collateral ligament reconstruction in Major League Baseball pitchers. *J Shoulder Elbow Surg*. 2013;22(5):642-646.

19. Jones KJ, Lazaro LE, Taylor SA, et al. Quantitative assessment of patellar vascularity following bone-patellar tendon-bone autograft harvest for ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(9):2818-2824.

20. Kimball JP, Glowczewskie F, Wright TW. Intraosseous blood supply to the distal humerus. *J Hand Surg Am*. 2007;32(5):642-646.

21. Lazaro LE, Cross MB, Lorich DG. Vascular anatomy of the patella: implications for total knee arthroplasty surgical approaches. *Knee*. 2014;21(3):655-660.

22. Lazaro LE, Sculco PK, Pardee NC, et al. Assessment of femoral head and head-neck junction perfusion following surgical hip dislocation using gadolinium-enhanced magnetic resonance imaging: a cadaveric study. *J Bone Joint Surg Am*. 2013;95(23):e1821-e1828.

23. Lazaro LE, Wellman DS, Klinger CE, et al. Quantitative and qualitative assessment of bone perfusion and arterial contributions in a patellar fracture model using gadolinium-enhanced magnetic resonance imaging: a cadaveric study. *J Bone Joint Surg Am*. 2013;95(19):e1401-e1407.

24. Liu JN, Garcia GH, Conte S, ElAttrache N, Altchek DW, Dines JS. Outcomes in revision Tommy John surgery in Major League Baseball pitchers. *J Shoulder Elbow Surg*. 2016;25(1):90-97.

25. Lynch JL, Maerz T, Kurdziel MD, Davidson AA, Baker KC, Anderson K. Biomechanical evaluation of the TightRope versus traditional docking ulnar collateral ligament reconstruction technique: kinematic and failure testing. *Am J Sports Med*. 2013;41(5):1165-1173.

26. Marshall NE, Keller RA, Lynch JR, Bey MJ, Moutzouros V. Pitching performance and longevity after revision ulnar collateral ligament reconstruction in Major League Baseball pitchers. *Am J Sport Med*. 2015;43(5):1051-1056.

27. McAdams TR, Lee AT, Centeno J, Giori NJ, Lindsey DP. Two ulnar collateral ligament reconstruction methods: the docking technique versus bioabsorbable interference screw fixation. A biomechanical evaluation with cyclic loading. *J Shoulder Elbow Surg*. 2007;16(2):224-228.

28. McGraw MA, Kremchek TE, Hooks TR, Papangelou C. Biomechanical evaluation of the docking plus ulnar collateral ligament reconstruction technique compared with the docking technique. *Am J Sports Med*. 2013;41(2):313-320.

29. Osbahr DC, Cain EL, Raines BT, Fortenbaugh D, Dugas JR, Andrews JR. Long-term outcomes after ulnar collateral ligament reconstruction in competitive baseball players: minimum 10-year follow-up. *Am J Sports Med*. 2014;42:1333-1342.

30. Paletta GA, Klepps SJ, Difelice GS, et al. Biomechanical evaluation of 2 techniques for ulnar collateral ligament reconstruction of the elbow. *Am J Sports Med*. 2006;34(10):1599-1603.

31. Rodeo SA, Arnoczky SP, Torzilli PA, Hidaka C, Warren RF. Tendon-healing in a bone tunnel: a biomechanical and histological study in the dog. *J Bone Joint Surg Am*. 1993;75(12):1795-1803.

32. Rohrbough JT, Altchek DW, Hyman J, Williams RJ, Botts JD. Medial collateral ligament reconstruction of the elbow using the docking technique. *Am J Sports Med*. 2002;30(4):541-548.

33. Sculco PK, Lazaro LE, Su EP, et al. A vessel-preserving surgical hip dislocation through a modified posterior approach: assessment of femoral head vascularity using gadolinium-enhanced MRI. *J Bone Joint Surg Am*. 2016;98(6):475-483.

34. Thomopoulos S, Williams GR, Gimbel JA, Favata M, Soslowsky LJ. Variation of biomechanical, structural, and compositional properties along the tendon to bone insertion site. *J Orthop Res*. 2003;21(3):413-419.

35. Thomopoulos S, Williams GR, Soslowsky LJ. Tendon to bone healing: differences in biomechanical, structural, and compositional properties due to a range of activity levels. *J Biomech Eng*. 2003;125(1):106-113.

36. Thompson WH, Jobe FW, Yocum LA, Pink MM. Ulnar collateral ligament reconstruction in athletes: muscle-splitting approach without transposition of the ulnar nerve. *J Shoulder Elbow Surg*. 2001;10(2):152-157.

37. Watson JN, McQueen P, Hutchinson MR. A systematic review of ulnar collateral ligament reconstruction techniques. *Am J Sports Med*. 2014;42(10):2510-2516.

38. Wavreille G, Dos Remedios C, Chantelot C, Limousin M, Fontaine C. Anatomic bases of vascularized elbow joint harvesting to achieve vascularized allograft. *Surg Radiol Anat*. 2006;28(5):498-510.

39. Wegmann K, Burkhart KJ, Koslowsky TC, Koebke J, Neiss WF, Müller LP. Arterial supply of the distal humerus. *Surg Radiol Anat*. 2014;36(7):705-711.

40. Whitson TB, Walmsey R. Some observations on the reactions of bone and tendon after tunnelling of bone and insertion of tendon. *J Bone Joint Surg Br*. 1960;42-B:377-386.

41. Wilson AT, Pidgeon TS, Morrell NT, Dasilva MF. Trends in revision elbow ulnar collateral ligament reconstruction in professional baseball pitchers. *J Hand Surg Am*. 2015;40(11):2249-2254.

42. Yamaguchi K, Sweet FA, Bindra R, Morrey BF, Gelberman RH. The extraosseous and intraosseous arterial anatomy of the adult elbow. *J Bone Joint Surg Am*. 1997;79(11):1653-1662.