Appendix 2

Surgical Techniques

Jobe[2,8]

First performed in 1974 and published in 1986, the Jobe technique was the first ever attempt at MUCL reconstruction. The surgery is performed under general anesthesia with an arm tourniquet on an arm board through a 10-cm curved incision, centered on the medial epicondyle. The medial antebrachial cutaneous and ulnar nerves are carefully protected. The fascia is divided in line with the fibers and a longitudinal split is made in the flexor aponeurosis and underlying muscles, in line with the fibers. To improve exposure, the tendinous origin of the flexor pronator muscle group was transected, leaving a small piece of tendon attached to the medial epicondyle for later repair, followed by distal reflection of the detached muscle group. This technique routinely frees the ulnar nerve proximally from the arcade of Struthers to the interval between the 2 heads of the FCU distally. A loop of 6.4-mm Penrose drain is placed around the ulnar nerve to protect it, and the intermuscular septum in the arm is released for approximately 5 to 8 cm. Calcifications and osteophytes are removed, and a 3.2-mm drill bit is then used on slow with a drill guide to drill 2 holes in the ulna and 3 in the medial epicondyle to correspond with the attachment sites of the anterior bundle of the MUCL. The holes are strategically placed to prevent the graft from rubbing on any bony prominences (medial epicondyle). The graft (originally described as either the palmaris longus, plantaris, or Achilles tendons) was passed in a figure-of-8 configuration and tightened down, making sure to avoid any valgus stress on the elbow during tensioning. The native

MUCL is sutured over the top for added strength. The ulnar nerve is then transposed submuscularly (under the flexor and pronator muscles), anterior to the medial epicondyle over the graft, and the flexor pronator muscles were reattached to the remnant stump that was left at the medial epicondyle. Care is taken to ensure the ulnar nerve is free. Absorbable sutures are used to repair the flexor pronator muscle to the stump of tissue. The tourniquet is released and the wound closed after hemostasis is achieved.

Modified Jobe[13]

This modification of the original Jobe technique popularized by Thompson does not transpose the ulnar nerve and splits the flexor pronator mass rather than transects it. The same incision and dissection is carried out as the original Jobe technique, but rather than transecting the flexor pronator tendinous insertion, this technique simply splits the muscles and does not detach them. Then, instead of a 3.2-mm drill bit, a 4.5-mm drill bit is used to create the humeral origin of the MUCL, followed by 3.5-mm drill bits to create the attachment sites on the humerus and ulna. The graft types were similar to the initial Jobe technique of palmaris, plantaris, and Achilles tendon grafts. The graft is fixed in a figure-of-8 fashion with support under the elbow to avoid valgus stress, followed by reinforcement with the native MUCL.

Docking[12]

While the Jobe and modified Jobe are similar, the docking technique has significant differences comparatively. The docking technique is performed under an axillary

block with an arm tourniquet, and an arthroscopic exam of the elbow is performed on every patient using an arm holder with the arm draped over the body to mimic the prone position. The arthroscope is inserted via a lateral portal, and an examination of the anterior compartment looking for loose bodies and cartilage damage is performed. A valgus stress test is then performed to evaluate the MUCL, which, according to the authors, is almost always torn if the joint gaps open more than 3 mm. The arthroscope is removed, the joint insufflated with saline, and the arthroscope is reinserted though a posterolateral portal to examine the posterior compartment. Any concomitant pathology is addressed (removal of loose bodies, osteophytes, etc), the arthroscope removed, the arm removed from the arm holder and placed on the hand table, and, if present, the ipsilateral palmaris tendon harvested via a 1-incision approach using a tendon stripper. A Krakow stitch is placed in 1 end and the tendon is stored in a moist sponge.

Once the tendon is harvested, the elbow is approached by an incision from the distal third of the intermuscular septum across the medial epicondyle and extending 2 cm distal to the end of the sublime tubercle. The dissection is carried down to the fascia of the FCU, which is incised longitudinally and split, followed by a split of the anterior bundle of the MUCL to expose the joint. Joint laxity is again confirmed (valgus stress producing >3 mm of joint laxity), and the areas for tunnel placement on the ulna are exposed. The posterior tunnel is placed 4 to 5 mm posterior to the sublime tubercle; care must be taken to avoid the ulnar nerve. At this stage, if the ulnar nerve subluxates anteriorly, or if the patient had preoperative ulnar nerve

symptoms, it is transposed for its protection. A 3-mm burr is used to make 2 ulnar tunnels with a 2-cm bone bridge in between them, 1 anterior and 1 posterior to the sublime tubercle. A curved curette is used to connect the tunnels but should not violate the bony bridge. The surgeon then uses a no. 1 Ethibond Excel OS2 needle to pass a 2.0 suture through the tunnel. The attention is turned to the humerus, and proper exposure of the projected tunnel is achieved by extension of the previous split in the MUCL proximally to its humeral origin and placing small blunt retractors to protect tissue around the tunnel site. A longitudinal humeral tunnel is created up the axis of the medial epicondyle to a depth of 15 mm using a 4-mm burr at the anterior half of the medial epicondyle in the anterior portion of the native MUCL. A dental drill with a small drill bit is then used to create 2 small puncture holes (approximately 0.5-1.0 cm apart) at the upper border of the medial epicondyle to allow suture passage from the primary humeral tunnel. A suture passer is used to pass the looped suture thorough each puncture hole for later graft passage.

Similar to other techniques, the docking technique requires forearm supination and varus stress at the elbow for securing the graft. The longitudinal split in the native MUCL is repaired, followed by graft passage from anterior to posterior in the ulnar tunnel (Figure 5A). The graft limb with the Krakow stitch already in place is passed into the humeral tunnel, and each suture is pulled through 1 of the puncture holes. Tension is held on the graft while the forearm is maximally supinated with a varus stress on the elbow, and the elbow is brought through flexion and extension to eliminate any creep in the graft, similar to an anterior cruciate ligament

reconstruction. The proper length of the free limb needed to properly tension the graft within the humeral tunnel is estimated, marked with a pen, and a Krakow stich is placed into the free limb. Excess graft is removed, and the free limb is now passed and docked securely in the humeral tunnel, with all sutures exiting through the puncture holes. Tension is held on the graft, a varus stress applied to the elbow, and the elbow ranged in flexion and extension to properly tension the graft. Once satisfied with the tension, the sutures are tied over the humeral bony bridge.

Docking Plus[10]

The docking plus technique, introduced in 2013 by McGraw et al, combines the docking technique with the figure-of-8 method for securing the graft. A similar exposure as the docking technique is performed. However, when drilling the ulnar tunnels at the insertion of the anterior bundle on the sublime tubercle, a V-shaped ulnar drilling guide is used with 2.7-mm drill bits to create 2 converging tunnels at a 55° angle, approximately 7 mm apart. A curette is used to ensure the tunnels connect and allow for graft passage, and once connected, a closed suture loop is passed though the tunnel. Similar to the docking technique, a 4-mm burr is used to make a longitudinal socket, 1.5 to 2 cm deep, at the origin of the anterior bundle of the native MUCL, followed by a 2.8-mm drill bit to create 2 exit holes, approximately 1 to 1.5 cm apart at a 45° angle to one another at the medial epicondyle, 1 anterior and 1 posterior. The ulnar nerve must be protected with blunt retractors at this step. The exit holes converge into the longitudinal socket. The graft is passed though the proximal ulnar tunnel and the 2 ends are measured such that 1 end sits flush

into the humeral tunnel. This short end is then sutured in a Krakow fashion to the long end, which is then inserted into the longitudinal humeral tunnel and out the posterior exit hole. The short end is now held in constant tension by an assistant. The excess graft is then wrapped around the epicondyle and fed back into the anterior hole and out the longitudinal tunnel, fed through the ulnar tunnel from lateral to medial, fed one last time through the humeral tunnel and out the anterior exit hole (opposite the short end), and finally tied down over the humeral bone bridge with the arm in 30° of flexion and without any valgus stress on the elbow. No. 0 FiberWire is used to both reinforce the tied suture ends and to suture the 4 graft strands together in a Krakow fashion just proximal to the ulnar bone bridge.

Dane-TJ[3]

The DANE-TJ (David Altchek, Neal ElAttrache, Tommy John) technique combines the docking technique of the humerus with the interference screw technique of the ulna. The approach and positioning is similar to the modified Jobe technique. Once down to fascia, the raphe at the anterior margin of the FCU is split longitudinally along with the underlying muscle to expose the MUCL. Once the MUCL was evaluated and reconstruction warranted, 15 cm of graft, either palmaris or gracilis tendon, was harvested, folded on itself, and a Krakow stitch placed for 25 mm on the folded end of the graft. A 15-mm-deep and appropriately wide ulnar tunnel based on the graft diameter is created on the sublime tubercle, angled to a point distal to the supinator crest on the lateral ulna. Two to three millimeters of bone was preserved between the tunnel and the articular surface of the joint. The ulnar nerve is only transposed if

symptomatic preoperatively. The humeral tunnel is then created at the origin of the MUCL using a 4.5-mm drill bit, followed by 2 smaller tunnels in the medial epicondyle drilled proximal to distal, spaced at least 5 mm apart, using a 2.7-mm drill bit, ensuring these both connect with the 4.5-mm tunnel. If necessary, based on graft size, the distal ends of the smaller tunnels are widened to allow for proper docking of the graft. An appropriately sized (same diameter to slightly smaller than the tunnel width) Biotenodesis screw is used for interference fixation of the graft to the ulna. Next, the elbow is reduced, the free ends of the graft measured for proper length, the excess graft cut, and Krakow stitches run in both free graft ends. The sutures are passed through the exit holes in the humerus and tightened. The native MUCL is then reapproximated, followed by tying of the sutures over the humeral bone bridge.

Double Docking[4,9]

The positioning and approach are the same as that of the standard docking technique. However, this technique differs from the standard docking in that a single, isometric drill hole is created based on the size of the graft in the ulna and humerus, requiring fixation on both bones. First, the center of the sublime tubercle is found and the ulnar hole is drilled with a 4.5-mm drill. Then, while a retractor is placed behind the ulna to protect the ulnar nerve, 2 divergent drill holes exiting the posterolateral cortex are drilled with a 0.0625-inch Kirschner wire. A 1-cm bridge is left between the 2 drill holes. The sutures of the prepared graft are passed through the holes using suture passers, and the sutures are tied over the cortex opposite the tunnel (Figure 5B).

Then, with the ulnar nerve protected, a 4.5-mm drill (occasionally a Kirschner wire is placed and overdrilled with a 4.5-mm cannulated drill) is used to drill the humeral tunnel at the UCL footprint on the anteroinferior aspect of the medial epicondyle. Once the tunnel is drilled, the graft is measured and cut at the appropriate length to allow docking into the humerus. The sutures are passed through the tunnel and tied over an endobutton on the posterior humerus. Alternatively, 2 divergent drill holes can be drilled in a similar manner as the ulna and tied over a bone bridge of at least 1 cm. Graft isometry is confirmed by taking the elbow through full range of motion.

Hybrid[5]

This technique, described in 2011, beings with the patient supine with the elbow on a hand table. The ipsilateral palmaris is harvested, if present, and if not, the contralateral palmaris or Achilles tendon is harvested prior to beginning the case. A modified Kessler stitch is placed on each end of the graft. A 6-cm incision is made, starting at the anterior proximal aspect of the medial epicondyle and continued distally. Once the flexor-pronator fascia is exposed, a longitudinal split is made in the posterior one-third of the muscle to expose the MUCL, which was then tested to confirm incompetency. The MUCL is obliquely cut and debrided. The humeral origin of the MUCL is identified and debrided, and a burr is then used to create a trough in the medial epicondyle in line with the origin of the MUCL and deep enough for the graft to be countersunk below the cortical surface. Two bioabsorable suture anchors are placed at the medial and lateral edges of the trough, taking care not to violate

the posterior cortex. Once properly seated, the sublime tubercle is exposed and a periosteal sleeve is lifted posteriorly (helps protect the ulnar nerve, which is only transposed if the patient has preoperative ulnar nerve symptoms). A 3.2-mm drill bit is used to make 2 oblique, convergent holes (at approximately 60° or 90°), followed by a curette and towel clip to ensure the hole is connected properly, taking care not to break the bone bridge. The joint is irrigated. The midpoint of the graft is fixed at the humeral suture anchors such that the graft lies in the trough, and the free ends of the graft are passed, 1 at a time, through opposite ulnar tunnels with the excess graft exiting the opposite tunnel it entered though. If the arm is flexed to 30° with a varus stress, the 2 ends are tensioned, and the ends are fixed to the proximal portion of the other arm with 2-0 nonabsorbable suture, followed by extra fixation with the leading sutures. Tension is checked, and the native MUCL is sutured to the anterior graft (thereby closing off the anterior joint), while the posterior joint is left open to minimize ulnar nerve damage.

ASMI Modification[1]

This technique involves similar set-up and positioning to Jobe, with each patient receiving a diagnostic arthroscopy prior to MUCL reconstruction. An 8-cm incision centered over the medial epicondyle is made. Dissection is carried down to the ulnar nerve, which is isolated and removed from the groove to allow visualization of the MUCL and capsule. To expose the MUCL, the flexor muscle is dissected off the anterior bundle at its distal insertion; the flexor pronator mass at the medial epicondyle is not released. The tunnel drilling and figure-of-8 configuration of the

graft is similar to Jobe[2,8]; a palmaris or toe extensor tendon graft is utilized. The elbow is placed at 30° with a varus stress when the graft is secured. Finally, the ulnar nerve is routinely transposed subcutaneously using a fascial sling technique.

Tension Slide[6]

Unlike the previously mentioned techniques, the tension slide technique focuses only on the ulnar fixation, with the premise of achieving interference screw fixation and a cortical button on the opposite cortex. As the only study to examine this technique is a biomechanical study, the clinical outcomes of the technique remain to be seen. To perform this technique, a 3.2-mm guide pin is placed bicortical, 5 cm distal to the joint line, on the flattened ridge of the ulna (do not place into the proximal radioulnar joint). Then, overdrill the guide pin (only the near cortex) with a 7-mm drill. The tendon graft is then folded over, whip-stitched, and threaded through a cortical button, which is advanced to the opposite cortex and flipped to secure it in place. The suture limbs must be pulled to advance the graft into the tunnel. After the graft is seated, a tenodesis screw is placed. To secure the screw, 1 of the free suture limbs is passed through the screw and 1 is passed though the graft. These are then tied over the top of the screw for increased fixation.

Bisuspensory[7]

This new technique uses suspensory fixation of both the humerus and ulna. This technique has only been reported in biomechanical studies using extensor digitorum longus (EDL) grafts, and as such, patient positioning and set-up, as well as

clinical correlation, are unknown. To perform this technique, the elbow is approached over the medial epicondyle and the entire MUCL is debrided and taken down, after which the origin and insertion are marked with a pen. A 3.2-mm guide pin is placed to a depth of 20 mm through the humeral origin of the MUCL in an ulnar to radial orientation, exiting the medial column anterior to what the extension of the intermuscular septum would be. A 4.5-mm cannulated drill is used to overdrill the guide pin to 15 mm and a tightrope is passed, leaving the loop out of the humeral insertion and putting the cortical button on the outer cortex. A loop is left to help pass the graft. The ulnar tunnel is created using a 3.2-mm guide pin as well, aimed distally and posteriorly 30° at the insertion site of the MUCL (should start the pin perpendicular to the ulna to prevent the pin from skiving off the bone, then adjust the angle to 30°); the tunnel should be a depth of 35 to 40 mm and exit the ulna on the posterior aspect of the interosseous ligament. A 4.5-mm cannulated drill is used to overdrill the guide pin to a depth of 30 mm. The pin is removed, the tightrope is again passed, and the button is flipped once past the far cortex to engage it. The tightrope is able to dunk the graft into the hole at both points. The graft is then introduced into the humeral tunnel first, and the toggle stitches are used to bottom out the graft in the tunnel. Once secured, the elbow is flexed to 30° and a varus stress is placed on the joint while the ulnar side of the graft is passed though the loop with approximately 4 cm of excess graft past the tunnel. This allows the graft to double up inside the ulnar tunnel. The graft is then passed in by the tightrope, and the excess graft is sutured to itself using No. 2 Ethibond in a figure-of-8 configuration. The graft undergoes final tightening.

Ziploop[11]

This technique involves Ziploop fixation at the ulna with the previously described docking technique at the humerus, supplemented with an interference screw. To perform the Ziploop technique on the ulna, the center of the insertion of the MUCL on the sublime tubercle is identified (roughly 5 mm distal to the joint line) and a 2.4-mm guide pin is passed at a 45° angle distal to the ulna, slightly medial to lateral, in an anterior to posterior direction. The guide pin is then overdrilled with a 6-mm reamer to the far cortex (do not perforate the far cortex), followed by a 4.5-mm reamer passed over the guide pin, which should perforate the far cortex, and the final length is measured. A gracilis autograft, doubled over and whip-stitched on each end using a No. 10 MaxBraid suture, is used for the graft. The midportion of the graft is placed into the loop of the Ziploop, which is shortened to equal the length of the ulnar tunnel previously measured. Then, 15 mm of graft is measured from the end and marked with a pen. A Beath pin is used to pass the Ziploop through the ulnar tunnel and deploy it with cortical fixation. The graft is tightened until 15 mm of graft is in the ulnar tunnel. The humeral side is fixed with the elbow at 45° and a varus stress applied in the usual fashion for the docking technique. However, in addition, a metal interference screw is placed into the humeral socket and the suture tied over the top.

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