Double-Barrel Remplissage: An Arthroscopic All—Intra-articular Technique Using the Double-Barrel Knot for Anterior Shoulder Instability

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Abstract: The arthroscopic remplissage procedure is an effective addition to a standard anterior repair in traumatic anterior shoulder instability associated with large humeral defects. The double-barrel remplissage is an all—intra-articular technique that uses a double-pulley, sliding, and self-retaining knot mechanism called the double-barrel knot. A 70° arthroscope (posterior portal) is necessary for adequate visualization of the humeral defect and the rotator cuff. Transtendon anchors (single or double loaded) are inserted into the superior and inferior aspects of the humeral defect through a cannula that is placed posterior to the infraspinatus. Placement of anchors is facilitated by insertion of a guidewire, as well as an anchor sleeve that is threaded over it. The double-barrel knot is formed using the anchors as a double-pulley system, and the knot is tensioned after the anterior repair is complete. Intra-articular visualization confirms adequate approximation and compression of the infraspinatus tendon and capsule into the defect. Advantages include an increased surface area (footprint) for healing and ease of knotting without the necessity for additional subacromial dissection.

The arthroscopic remplissage procedure combined with anterior labral repair or reconstruction is an effective procedure to treat anterior glenohumeral instability associated with significant humeral bony defects.[1] Clinical studies have shown good to excellent outcomes at intermediate- and long-term follow-up, and biomechanical studies have shown advantages of the combined procedure.[2,3] Current remplissage techniques involve several steps, which increase the amount of time required for the procedure; these steps include (1) glenohumeral preparation with placement of 1 or 2 anchors; (2) shuttling of sutures through the infraspinatus tendon; (3) additional subacromial bursectomy for suture retrieval and subsequent knot tying; and (4) shifting the arthroscope back and forth between the glenohumeral and subacromial spaces for anchor placement, knot tying, and assessment of infraspinatus approximation.

The purpose of this report is to describe a modification of the arthroscopic remplissage procedure. This technique is performed entirely through the glenohumeral joint (all—intra-articular) and uses a double-pulley, sliding, and self-retaining knot configuration (double-barrel knot [DBK]) devised by the author to secure the capsulotenodesis.[4]

Technique

The procedure is performed with the patient in the standard beach-chair position, and the arm is supported by an upper-limb positioner (Trimano; Arthrex, Naples, FL). Four portals (standard anterior and posterior portals, anterolateral portal, and axillary-pouch portal) are used in this procedure (Fig 1). A 30° arthroscope (posterior portal) is used for diagnostic arthroscopy, and the anterior and anterolateral portals are established. The double-barrel remplissage is performed before the labral reconstruction. The key steps and surgical pearls of the technique are summarized in Tables 1 and 2, respectively, and the steps are demonstrated in Video 1.

Step 1: Visualization of Remplissage

A 70° arthroscope (posterior portal) is used, and the arm positioner is used to position the arm in 30° of abduction and forward flexion. This enables an "end-on"

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The author reports that he has no conflicts of interest in the authorship and publication of this article.

Received September 8, 2014; accepted November 6, 2014.

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2212-6287/14769

http://dx.doi.org/10.1016/j.eats.2014.11.006

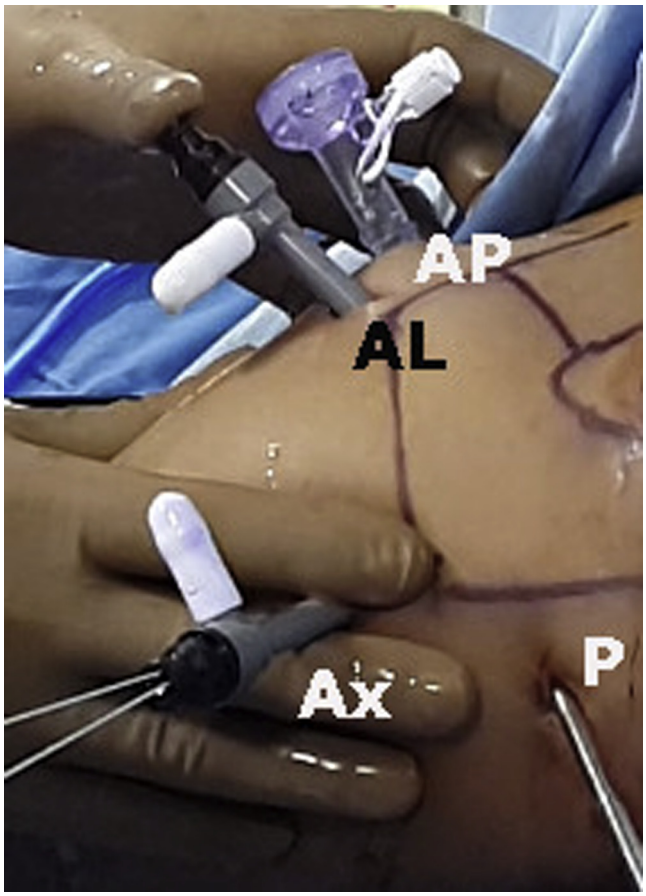

Fig 1. The left shoulder is shown positioned in the beach-chair position. The portals used for combined double-barrel remplissage and anterior instability repair are shown. The posterior (P) portal is used as the viewing portal (30° and 70° arthroscopes) throughout the procedure. The axillary-pouch (Ax) portal is placed 1 to 2 cm below the inferior border of the posterolateral acromial angle. (AL, anterolateral portal; AP, anterior portal.)

Table 1. Key Steps of Procedure

Visualization of the remplissage is facilitated by use of a 70° arthroscope (posterior portal) and proper positioning of the arm with an arm positioner.
Preparation of the humeral defect is performed with straight and curved shaver blades (anterolateral portal).
An axillary-pouch portal is placed as guided by a marker needle, and a cannula is placed posterior to the infraspinatus.
Anchors are inserted in the superior and inferior regions of the humeral defect. A portal dilator system and anchor sleeve are used to facilitate atraumatic trans-tendon anchor placement.
A double-barrel knot is created as described, and the knot is not tensioned until the anterior repair is completed.
Anterior and superior labral reconstruction is performed using double-loaded anchors.
Remplissage is completed by alternate tensioning of the suture strands in the axillary-pouch portal cannula, and the approximation is confirmed by intra-articular visualization.

view of the entire humeral head defect, and the surrounding rotator cuff and capsule are adequately visualized through the posterior portal.

Step 2: Preparation of Humeral Defect

An arthroscopic shaver (4-mm SabreTooth; Arthrex) is introduced through the anterolateral portal, and this permits adequate access for debridement of the Hill-Sachs defect. A curved shaver blade (4-mm SabreTooth Curved; Arthrex) is necessary for access to the most inferior region of the defect.

Step 3: Superior Anchor Insertion

An axillary-pouch portal is created approximately 1 to 2 cm inferior to the posterolateral angle of the acromion as described by Bhatia et al.[5,6] The exact site is located using a spinal needle that should pass through the upper infraspinatus tendon (Fig 2). A 5.5 × 70—mm cannula (Universal Cannula; ConMed Linvatec, Largo, FL) is placed posterior to the infraspinatus at this level, without penetrating the tendon. A 1- to 2-mm rigid guidewire is passed through this cannula and penetrates the infraspinatus to enter the glenohumeral joint. A dilator (Hip Arthroscopy Portal Dilation System; Arthrex) is passed over the guidewire to create an atraumatic passage. A 3-mm anchor sleeve (Arthrex) is passed over this wire and is used to place a 2.8-mm single- or double-loaded titanium anchor (Arthrex) in the superior aspect of the humeral defect (Fig 3A). Alternately, double-loaded bioabsorbable anchors (Bio-FASTak or Bio-SutureTak; Arthrex) may be used for the remplissage. The titanium eyelet is oriented vertically, and the inferior of the 2 suture strands is shortened. The sleeve is then withdrawn out of the cannula, and the cannula is directed inferiorly.

Step 4: Inferior Anchor Insertion

The guidewire is reinserted by directing it inferiorly, and it should now penetrate the infraspinatus and capsule adjacent to the inferior aspect of the humeral defect (Fig 3B). The length of the tendon bridge between the guidewire and superior anchor sutures is checked, and the guidewire is adjusted to maintain an adequate bridge. The dilator and anchor sleeve are reinserted over the wire, and a second anchor is passed in the inferior aspect of the humeral defect. The eyelet is again oriented vertically, and now the superior of the 2 suture strands is shortened. The anchor sleeve is withdrawn, and the 2 sets of sutures are held separately to prevent subsequent entanglement of sutures (Fig 3C).

Step 5: DBK

Next, a sliding and self-retaining DBK is created as described by Bhatia.[4] The short suture strands from each anchor are tied together securely to form a loop (Fig 4). The DBK throws are placed, and the knot is

Table 2. Technical Pearls for Key Steps of Procedure

Steps	Pearls
Visualization	Make the posterior viewing portal slightly medial to its usual location and position the arm in 30° of abduction and forward flexion to better visualize the repair.
Anchor insertion	Pass the rigid trans-tendon guidewire and sleeve above and below the humeral head to avoid cartilage damage. Use a dilator over the guidewire to ensure smooth passage of the sleeve.
	Pass the anchors into the humeral defect lateral to the articular cartilage to avoid inadvertent penetration of the articular cartilage; this may happen if the sleeve angulation is excessive.
DBK formation	Create a loop by tying the short sutures in the axillary-pouch portal cannula, and form the knot using this loop as an initial hitch. Ensure that the sutures are sliding within the individual anchors before tying the loop.
	For optimal sliding, place the anchors 1 to 2 cm apart.
	When double-loaded anchors are being used, the sutures must be segregated as soon as each anchor is passed to prevent entanglement.
Final approximation of infraspinatus into humeral defect	Perform this step after all other repairs are complete.
	Tension the DBK with alternate and equal pulling on the free strands. This maintains the knotted part of the loop in the center of the construct.
	Use a knot pusher for final tightening. Thread the knot pusher into each strand, and apply pressure on the knot without using the "past pointing" manoeuvre.
	Finally, secure the knot with 5 half-hitches, with alternating posts and throws.
	Cut the free suture ends by threading a closed-end knot pusher (Arthrex) over the sutures until the knot is felt. This cuts the sutures 1 to 2 mm from the last hitch, without the necessity to visualize the knot.

DBK, double-barrel knot.

formed; however, at this stage, the knot is not tensioned, and the long strands are clamped together outside the cannula.

Step 6: Labral Reconstruction

The arthroscope is changed to a 30° view from the posterior portal; alternately, use of the 70° arthroscope may be continued for anterior repair. Two or three anchors (Bio-SutureTak [Arthrex] or Gryphon [DePuy Mitek, Raynham, MA]) are inserted on the anterior glenoid rim through the anterior portal. A suture-passing device (Labral Scorpion; Arthrex) is used to pass sutures through the anterior capsulolabral tissue, and sliding knots are tied to reconstruct the torn anterior labrum; any other associated pathology (e.g., SLAP tear, humeral avulsion of anterior glenohumeral ligaments, or rotator cuff tear) is treated before the remplissage.

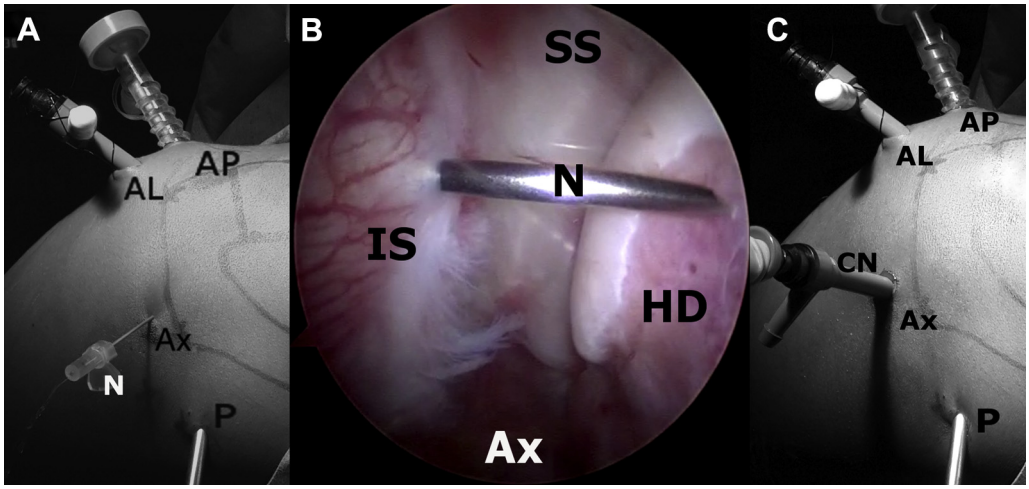

Fig 2. Placement of axillary-pouch portal. (A) A marker needle (N) is placed through the infraspinatus approximately 1 to 2 cm below the posterolateral acromial angle. (B) The needle (N) is visualized from the glenohumeral side and should be at the level of the superior aspect of the humeral defect (HD). (C) A cannula (CN) is placed posterior to the infraspinatus at this site and is used to place both anchors sequentially. (AL, anterolateral portal; AP, anterior portal; Ax, axillary-pouch recess portal; IS, infraspinatus; P, posterior portal; SS, supraspinatus.)

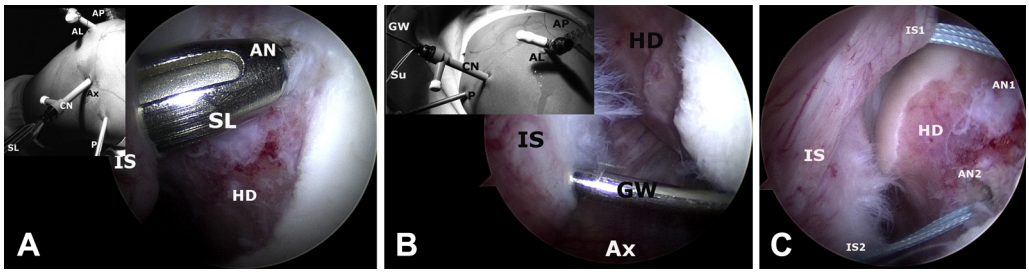

Fig 3. (A) Trans-tendon superior anchor insertion through a 70° arthroscope placed in the posterior portal (P). The anchor sleeve (SL) penetrates the infraspinatus tendon (IS) lateral to the musculotendinous junction through the axillary-pouch portal cannula (CN, inset), and this provides the correct angle and site of insertion for the superior anchor (AN) into the humeral defect (HD). (B) The inferior guidewire (GW) is inserted through the axillary-pouch portal cannula (CN). The wire is angled inferiorly (inset) and should exit the infraspinatus (IS) under the humeral head (HD). The sutures (Su) from the superior anchor remain in the same cannula and are held separated from the sleeve. (C) The 2 sets of sutures exit above (IS1) and below (IS2) the anchor insertion sites (AN1 and AN2, respectively), thereby creating a large tendon bridge (IS) between them. (AL, anterolateral portal; AP, anterior portal; Ax, axillary-pouch recess portal.)

Step 7: DBK Tensioning and Remplissage Completion

Once the anterior repair is complete, the remplissage is performed by simply pulling on the long suture strands alternately; this maneuver pulls the sliding knot into the cannula, and the loop compresses the infraspinatus tendon bridge and capsule into the humeral defect. The contact area and approximation of the infraspinatus are confirmed using the 70° view (posterior portal), and if inadequate, further contact can be achieved by pulling on the suture strands alternately (Fig 5). Final tightening is performed by using a knot pusher over each suture strand, and the knot is pushed further in. The self-retaining nature of the knot prevents loss of infraspinatus approximation as the knot is progressively tightened. The humeral head is rotated to confirm the integrity of the remplissage. The knot is locked in position by placing 5 half-hitches over the initial construct. The construct need not be visualized through the subacromial space, and the sutures are cut using a closed-end knot cutter (Arthrex) passed through the axillary-pouch portal cannula.

The rehabilitation protocol involves early passive rotation and forward flexion, and these are initiated in the first postoperative week. The rest of the protocol is similar to that of an anterior labroplasty/labral instability repair.[4]

Discussion

The remplissage procedure is usually performed using a combined glenohumeral and subacromial arthroscopic approach.[7,8] This necessitates back-and-forth shifting of the arthroscope between the glenohumeral and subacromial spaces. Moreover, subacromial

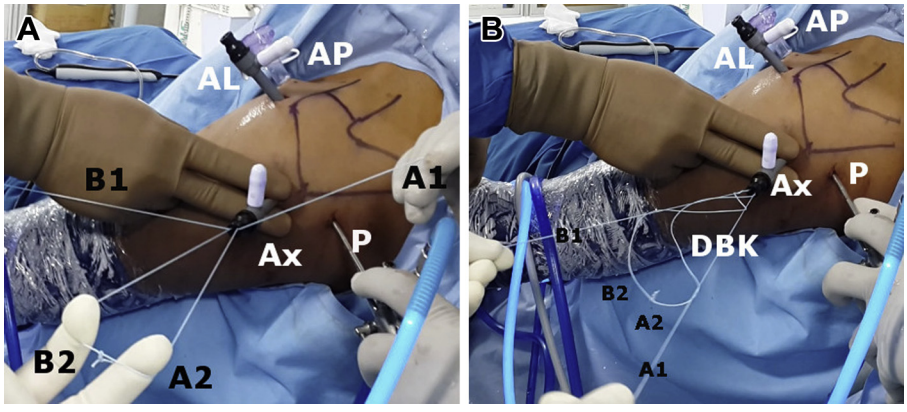

Fig 4. Formation of double-barrel knot. (A) The suture strands of the superior anchor (A1 and A2) and the strands of the inferior anchor (B1 and B2) are shown. The shortened sutures (A2 and B2) of each anchor are tied together to create the first loop. The longer strands (A1 and B1) are held taut to prevent entanglement in the axillary-pouch portal cannula. (B) Two additional loops are placed over the initial loop to create the final double-barrel knot (DBK) configuration. The knot is pulled onto the infraspinatus tendon bridge by alternately pulling on strands A1 and B1. (AL, anterolateral portal; AP, anterior portal; Ax, axillary-pouch recess portal; P, posterior portal.)

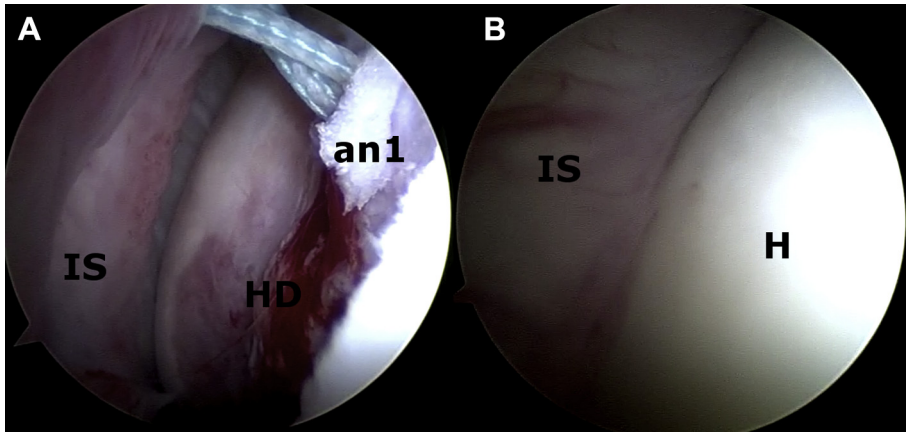

Fig 5. (A) The humeral defect (HD) is visualized through the 70° arthroscope (posterior portal) before final tensioning, and the sutures are tensioned to pull the knot and the infraspinatus (IS) tendon into the defect. (B) The infraspinatus is seen completely approximated into the humeral defect up to the junction of the humeral head cartilage (H). (an1, superior anchor.)

bursectomy is often necessary to visualize and retrieve sutures for knot tying. These steps add to the complexity of the procedure and prolong surgical time. The double-barrel remplissage is performed entirely from the intra-articular side, without any subacromial dissection, and thereby reduces surgical time. The technique has several advantages, as well as some potential limitations, over previously described techniques, and these are summarized in Table 3.[9-11]

Table 3. Advantages and Pitfalls of Double-Barrel Remplissage Technique

Advantages
The double-barrel knot does not require direct subacromial visualization for tying. This prevents the necessity for subacromial bursectomy and thereby does not violate the subacromial space.
The sliding and self-retaining nature of the knot allows predictable tensioning, and intra-articular assessment of approximation is a good indicator for appropriate tension.
The 2-anchor technique permits a "footprint" approximation of the infraspinatus into the humeral defect, and this increases the surface area for healing of the capsulotenodesis.
The technique is simple, has a short learning curve, and significantly reduces operative time for the combined instability repair.
Pitfalls
Visualization from the posterior portal may be impaired in the presence of synovitis or capsular stiffness. Inadequate visualization will result in incorrect assessment of the tendon bridge.
Sutures should be placed through the tendinous part of the infraspinatus. Medial placement results in excessive tissue approximation and may be a cause of postoperative stiffness.
Inferior guidewire placement may result in injury to the axillary nerve if the wire is inadvertently passed below the axillary pouch. This is prevented by intra-articular visualization of the guidewire entry into the glenohumeral joint.
Suture mismanagement in the axillary-pouch portal cannula will result in improper knotting, especially when double-loaded anchors are used. This is prevented by immediate segregation of each set of sutures as soon as the anchor is passed.
Poor sliding of the knot may occur if the anchors are placed too far from each other or if the anchors are placed too deep into the humeral head, and this will result in inadequate approximation of the infraspinatus into the defect.

The DBK is a double-suture knot that can be used in single-pulley (1-anchor) or double-pulley (2-anchor) configurations.[4] The knot has predictably good sliding capability even in a double-pulley configuration, and backing out of the knot is prevented by the figure-of-8 loop creation over the initial loop. This allows the tension to be retained in the system, and the approximation increases with every alternate pull on the sutures. The knot has been described for use in labral and rotator cuff tears, as well as in reconstruction of bony Bankart lesions; however, its utility in the remplissage technique has not been described before. Magnetic resonance imaging analysis during follow-up in a large number of patients has shown predictable healing of the infraspinatus tendon into the humeral defect with this technique (unpublished data, D.N.B., 2014). A biomechanical study is currently ongoing to determine the biomechanical properties of the DBK and other remplissage techniques.

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