Technical Note

The "Greenhouse" Technique Using Knotless Single-Row Suture Bridge Combined With Bone Marrow Stimulation for the Arthroscopic Treatment of Rotator Cuff Tears

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Abstract: To simplify the arthroscopic rotator cuff repair technique and improve tendon healing, we have developed a method named the "Greenhouse" technique to repair rotator cuff. With bone marrow stimulation combined with knotless single-row suture bridge fixation, we provide a technique for reliable cuff fixation with enhanced biological features.

Rotator cuff tear is a common shoulder disease in the aging population. Although the clinical results of arthroscopic rotator cuff repair have been promising, achieving tendon healing remains a challenge. There are 2 strategies to enhance tendon healing: mechanically and biologically. The mechanical approach is achieved by various suture methods. Suture-bridge repair was introduced by using 2 rows of anchors to improve tendon-to-bone contact over the footprint, together with decreased motion on the bone—tendon interface and increased resistance to rotational forces.[1-4] Although this technique leads to several advantages over the standard single-row or double-row repair, the incidence of retear cannot be avoided.[4-7] The most possible explanations may include greater tension for the repaired tendon than expected; tendon strangulation caused by medial row knot-tying; and further damage to the degenerated torn tendon.[8-11] The later introduced modified suture bridge technique with knotless medial row anchor can avoid some of the aforementioned disadvantages stated, and satisfactory early clinical results have been reported in the literature.[12]

Another approach to enhance tendon healing is biological augmentation, such as bone marrow stimulation (BMS). BMS is believed to provide an infusion of marrow elements such as cytokines, growth factors, and mesenchymal stem cells, which may enrich the local biological healing milieu.[13-15] It was described as a "crimson duvet" by Snyder and Burns[16] in 2009 for repairing large rotator cuff tear, with promising clinical outcomes.

We describe a method that combines BMS with a knotless single-row suture bridge technique together to provide full cover of the rotator cuff on the footprint and biological enhancement. This method is named the "Greenhouse" technique because of its similarity to irrigation and fertilization of plants in a greenhouse, with the canopy that enhancing footprint reconstruction (Figs 1 and 2). It is an easy arthroscopic technique that provides better tension control and biological stimulation. In addition, it also reduces the surgery costs by using fewer anchors.

Surgical Technique (With Video Illustration)

The Greenhouse technique is very simple and performed with 1 or 2 footprint knotless anchor and a 2-mm awl for BMS.

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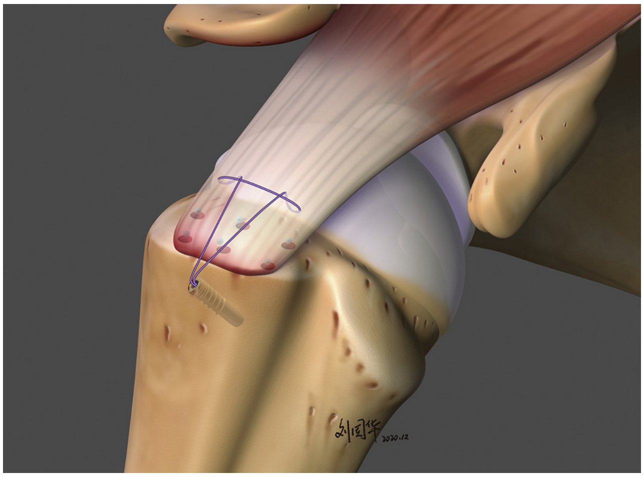

Fig 1. Illustration of the "Greenhouse" technique on a right shoulder. The ORTHOCORD polyester suture thread passed through the torn tendon in in a modified Mason–Allen way without knotting. Six holes were made on the greater tuberosity to perform BMS. The thread is then passed through the eyelet of a footprint anchor. After tightening the thread, the anchor is screwed in at the distal part of the greater tuberosity. (BMS, bone marrow stimulation.)

Fig 3. On a patient with a right rotator cuff tear, 5 portals were marked and are set up with the patient in the beach-chair position. (a) Anterior portal; (b) anterior lateral portal; (c) posterior lateral portal; (d) posterior portal; and (e) BMS portal. (BMS, bone marrow stimulation.)

Setup

The patient is placed in a beach-chair position under general anesthesia and interscalene block. Five portals are used for this technique: the posterior portal is made 2 cm inferior and 1 cm medial to the posterolateral corner of the acromion, the anterior portal is made lateral of the coracoid process and 2 cm inferior to the anterior acromial corner, the anterior lateral portal and posterior lateral portal are placed parallel and 3 cm lateral to the distal acromion and separately at least 5 cm apart, and the BMS portal is made close to the lateral side and on the midline of acromion (Fig 3).

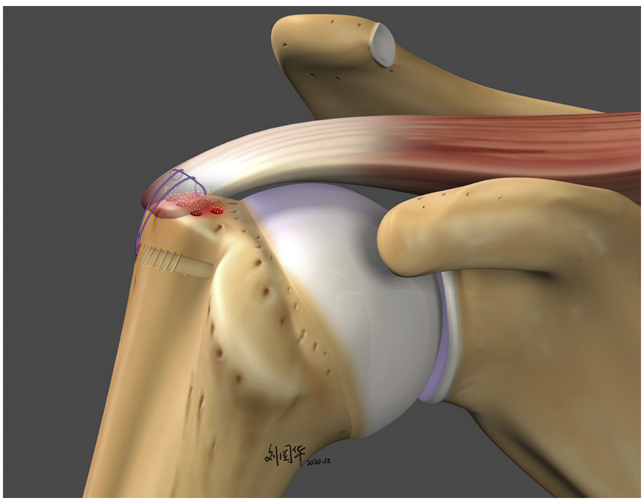

Fig 2. Illustration of the effect of "Greenhouse" technique on a right shoulder. With this technique, the rotator cuff is repaired by one footprint anchor without a medial row anchor. Combined BMS creates the clot, which flows out through the bone marrow. This technique pulls the rotator cuff tendon to fully cover the greater tuberosity, which prevents most of bone marrow cell extravasation too far away from tendon–bone surface. It is similar to irrigation and fertilization of plants in a greenhouse. (BMS, bone marrow stimulation.)

Evaluation of the Glenohumeral Joint

The glenohumeral joint is examined first by using a 30° arthroscope. If pathologic long head of the biceps tendon is identified, tenotomy or tenodesis is performed. Capsular release is performed if adhesions exist. The rotator cuff tear is identified and evaluated.

Subacromial Decompression and Rotator Cuff Repair Preparation

The 30° arthroscope is reinserted from the posterior portal to the subacromial space. Subacromial bursectomy with decompression is performed from the anterior lateral portal. Acromioplasty is performed if acromial impingement observed. Then, the arthroscope

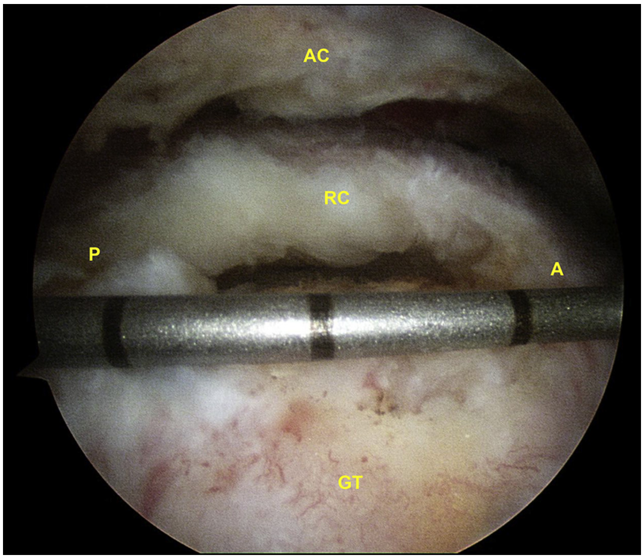

Fig 4. The torn tendon is evaluated in the subacromial space with scope in the anterior lateral portal. The torn tendon is measured by calibrated probe through the posterior portal, which shows 1 cm anterior to posterior in diameter of the tear. This view of right shoulder was taken with the patient in the beach-chair position. (A, anterior; AC, acromial; GT, greater tuberosity; P, posterior; RC, rotator cuff.)

is switched from the posterior portal to anterior lateral portal. The shape and quality of rotator cuff tears are evaluated. The tendon footprint is decorticated using the motorized shaver blade, and the size of tear is measured by a calibrated probe (Fig 4).

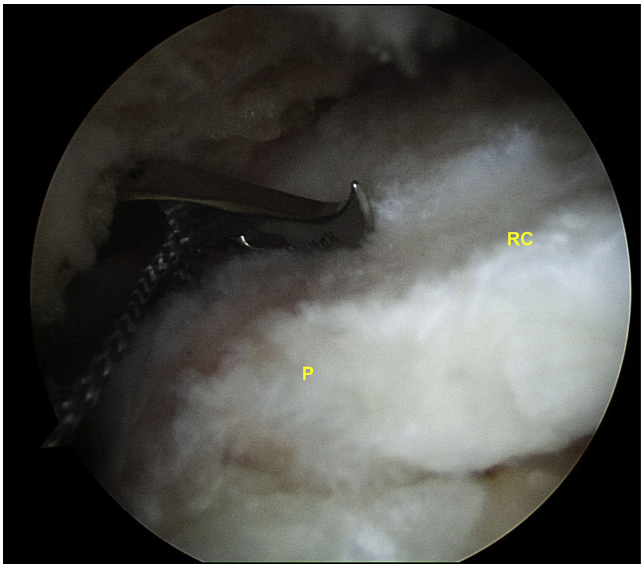

Fig 5. A CleverHook is used to hold the suture thread passing through the posterior portal, prepared to penetrate the edge of tendon from the bursal side to the articular side. This view of right shoulder was taken in the subacromial space with the scope in the posterior lateral portal and the patient in the beach-chair position. (P, posterior; RC, rotator cuff.)

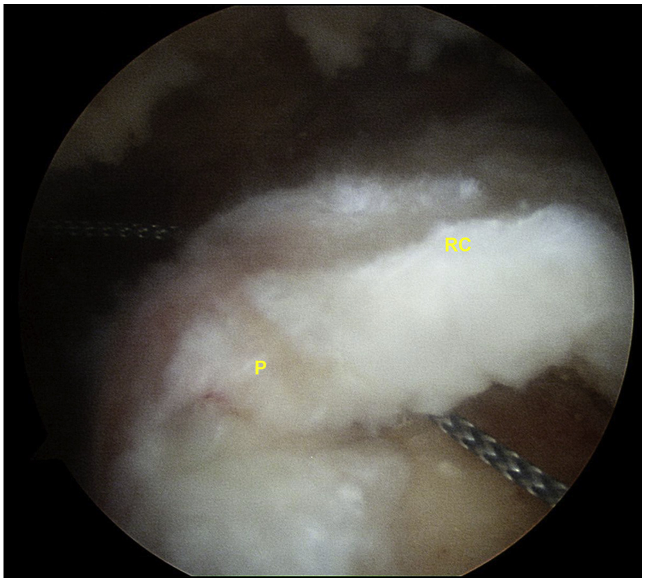

Fig 6. The suture thread is passed through the posterior edge of torn tendon, which is lateral to the muscle–tendon unit with CleverHook retrieved. This view of right shoulder was taken in the subacromial space with the scope in the posterior lateral portal and the patient in the beach-chair position. (P, posterior; RC, rotator cuff.)

"Greenhouse" Technique for Rotator Cuff Repair

The ORTHOCORD polyester suture thread (Johnson & Johnson, New Brunswick, NJ) is first passed through the posterior medial side of torn tendon using a tissue

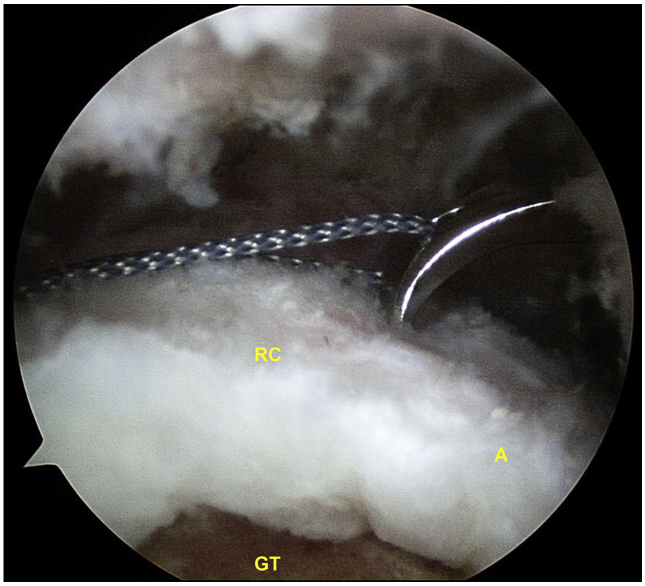

Fig 7. The CleverHook is used passing through anterior portal to hold the other end of thread on the bursal side of the tendon. The thread is prepared to penetrate through the anterior edge of torn tendon from the bursal side to the articular side with help of the CleverHook. This view of right shoulder was taken in the subacromial space with the scope in the posterior lateral portal and the patient in the beach-chair position. (A, anterior; GT, greater tuberosity; RC, rotator cuff.)

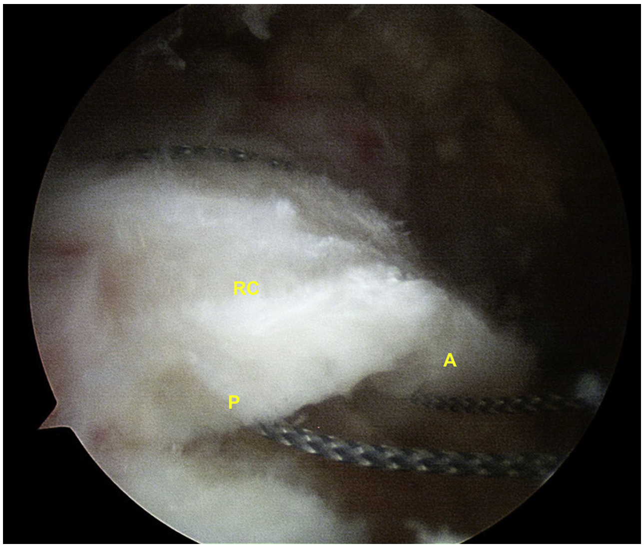

Fig 8. A suture loop is made over the bursal side with the CleverHook retrieved. This view of right shoulder was taken in the subacromial space with the scope in the posterior lateral portal and the patient in the beach-chair position. (A, anterior; P, posterior; RC, rotator cuff.)

penetrator from the bursal side to the articular side through posterior portal (Figs 5 and 6). The other free end of the suture is passed through the anterior medial side of the torn tendon, which is approximately 10 mm

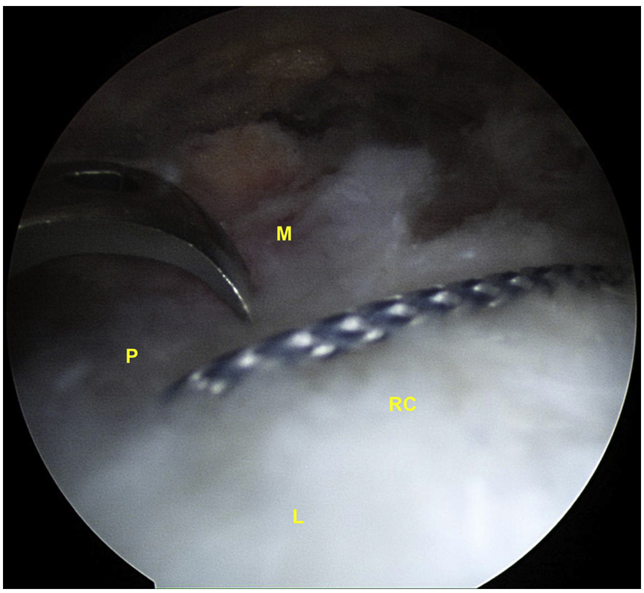

Fig 9. The CleverHook is used again, penetrating the posterior edge of tendon from the bursal side to the articular side through the posterior portal to catch the posterior free end of the suture. The position of penetration is 2 mm medial to the initial posterior suture point and medial to the loop. This view of right shoulder was taken in the subacromial space with the scope in the posterior lateral portal and the patient in the beach-chair position. (L, lateral; M, medial; P, posterior; RC, rotator cuff.)

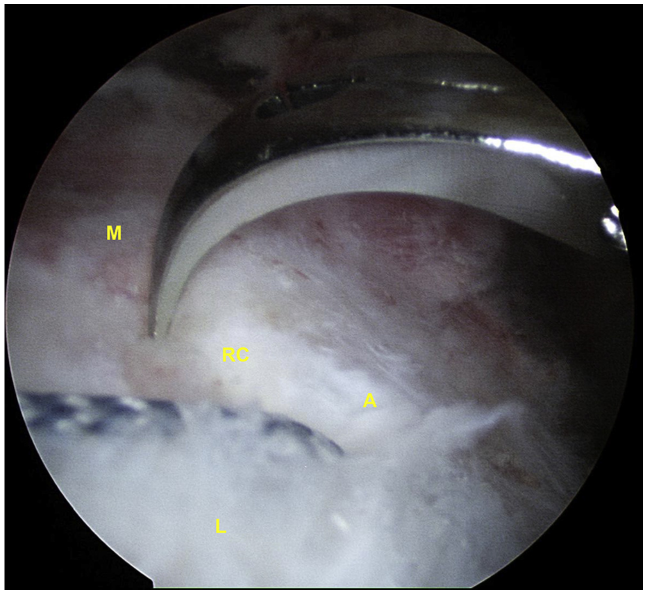

Fig 10. The CleverHook is used, penetrating the anterior edge of tendon from the bursal side to the articular side through the anterior portal to catch the anterior free end of the suture. The position of penetration is 2 mm medial from the initial anterior suture point and medial to the loop. This view of right shoulder was taken in the subacromial space with the scope in the posterior portal and the patient in the beach-chair position. (A, anterior; M, medial; L, lateral; RC, rotator cuff.)

from the first point. The suture now makes a loop over the bursal side (Figs 7 and 8). Then, the 2 free ends of the suture are pulled by a CleverHook (DePuy Synthes,

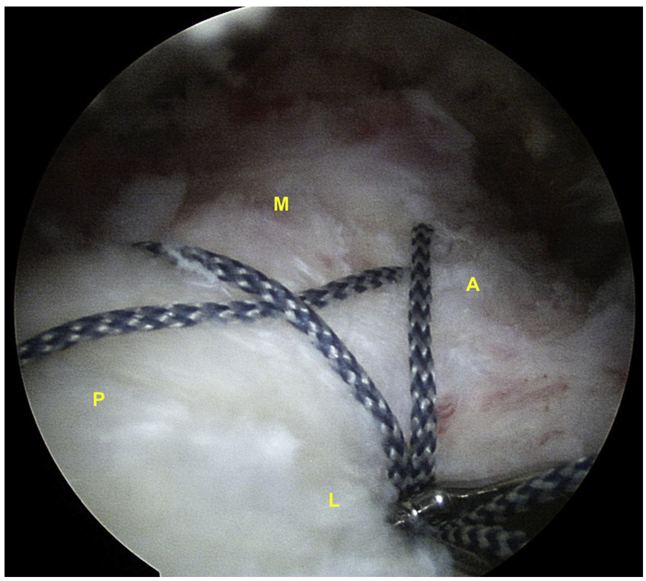

Fig 11. The thread is used to suture the torn tendon in a modified Mason–Allen fashion without knotting. Two free ends of thread are held by the suture retriever through the anterior lateral portal with scope in the posterior lateral portal under the subacromial space. (A, anterior; M, medial; L, lateral; P, posterior.)

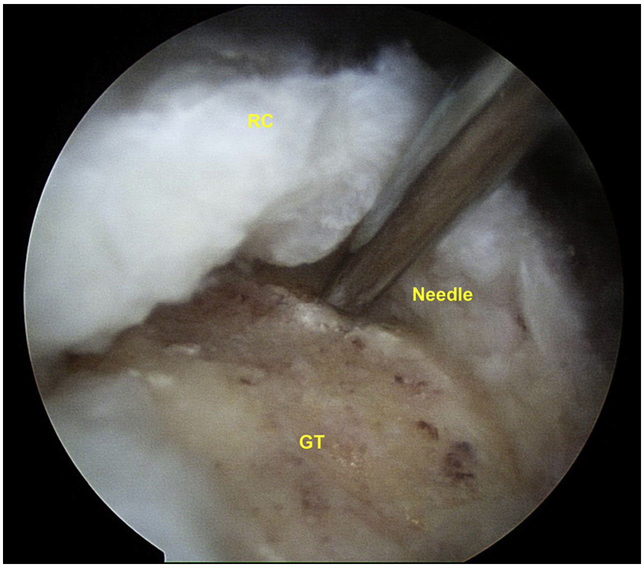

Fig 12. Before loading with the lateral row footprint anchor, the torn tendon is left to expose the bone bed. The BMS portal is set up with a needle passing through BMS portal to obtain the proper position to create the bone holes. This view of right shoulder was taken in the subacromial space with the scope in the posterior lateral portal. (BMS, bone marrow stimulation; GT, greater tuberosity; RC, rotator cuff.)

Warsaw, IN), which penetrates 2 mm medial to the initial suture point separately through the loop from the bursal side (Figs 9 and 10). Subsequently, the thread

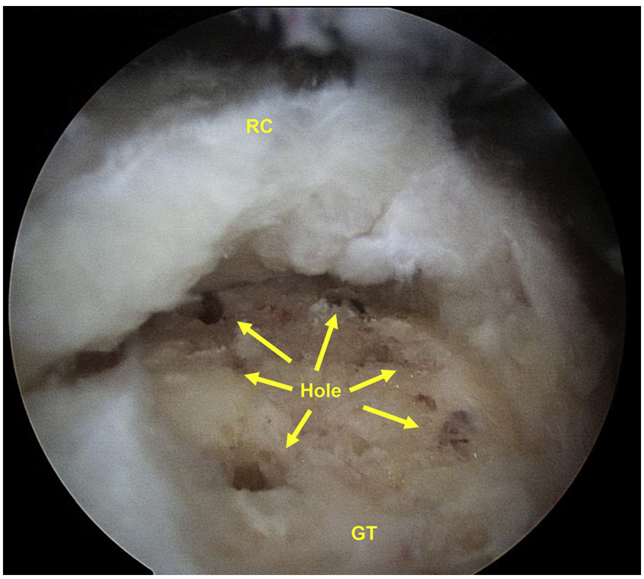

Fig 13. Six holes 5 mm apart and 1 cm in depth are created due to the area of exposed bone bed by the 2-mm diameter awl through BMS portal. This view of right shoulder was taken in the subacromial space with the scope in the posterior lateral portal with the patient in the beach-chair position. The arrows show each hole on the greater tuberosity. (BMS, bone marrow stimulation; GT, greater tuberosity; RC, rotator cuff.)

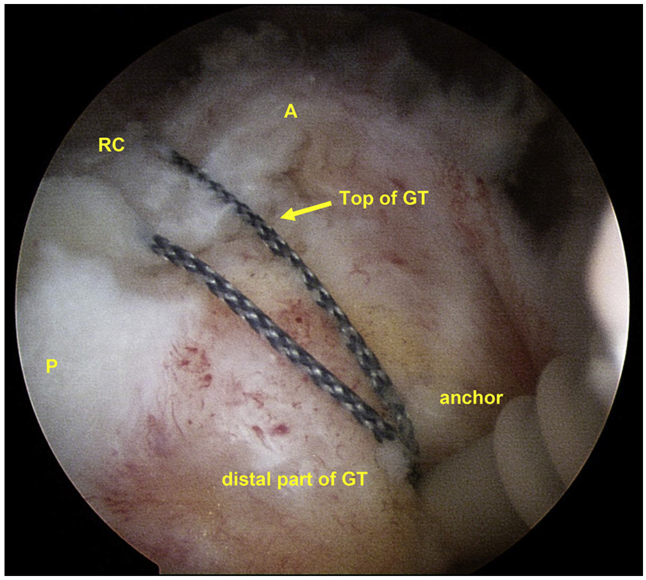

Fig 14. Two ends of the suture thread are locked with the lateral row footprint anchor. The anchor is inserted at the distal part of the greater tuberosity. This view of right shoulder was taken in the subacromial space with the scope in the posterior lateral portal and the patient in the beach-chair position. The arrow shows the top of the greater tuberosity. (A, anterior; P, posterior; GT, greater tuberosity; RC, rotator cuff.)

sutures the torn tendon in a modified Mason−Allen fashion without knotting (Fig 11). A needle is inserted through BMS portal to identify the proper position for

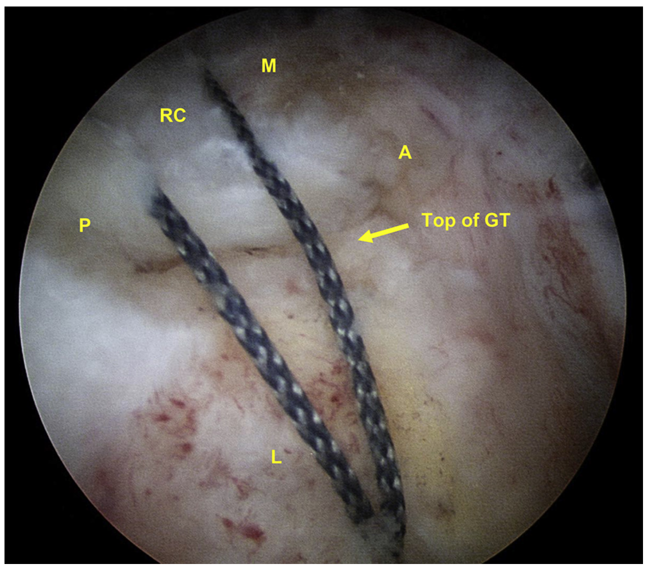

Fig 15. By tightening the thread and locking with the footprint anchor, the torn tendon is pulled back to original site and fully covering all holes created on the greater tuberosity. This view of right shoulder was taken in the subacromial space with the scope in the posterior lateral portal and the patient in the beach-chair position. The arrow shows the top of the greater tuberosity. (A, anterior; GT, greater tuberosity; M, medial P, posterior; RC, rotator cuff.)

Table 1. Pearls and Pitfalls of This Technique

Pearls	Pitfalls
1. When the tendon is penetrated, the position should be lateral to the muscle−tendon interface to avoid damage to muscle	1. The penetration position is too medial to the muscle−tendon interface, which would damage the muscle
2. When the anterior-to-posterior diameter of tear is greater than 1 cm, an additional thread should be used in the sameMason−Allen fashion	2. When the anterior-to-posterior diameter of tear is greater than 1 cm, suturing the tendon with just one thread would result in a "dog-ear" deformity
3. A lateral row footprint anchor should be inserted at the distal par t of the greater tuberosity (at least 2 cm distal to the top of greater tuberosity) to let the rotator cuff fully cover the all BMS holes	3. Inserting lateral the suture bridge anchor too close to the top of the greater tuberosity leaves parts of the BMS holes uncovered
4. A 2-mm diameter awl should be chosen to create holes on the greater tuberosity with a 1-cm depth and 5 mm apart until blood clots extravasate from bone marrow to create BMS effect	4. Holes that are too large, too close to each other, and more than 1 cm depth add the risk of damage to the bone
5. Elderly patients with severe osteoporosis should be excluded to prevent bone crush	5. BMS would add risk of bone damage due to severe osteoporosis
6. Both passive and active shoulder abduction are avoided for 4 weeks postoperatively.	6. Shoulder abduction in the early postoperatively may delay the tendon healing, since the torn tendon cannot obtain complete contact without medial tying

BMS, bone marrow stimulation.

BMS on the bone (Fig 12), followed by a 2-mm diameter awl to create holes on the greater tuberosity with a 1-cm depth and 5 mm apart until blood clot extravasates from the bone marrow. Holes are made according to the area of exposed footprint (Fig 13). Then, the 2 ends of the suture are retrieved through anterior lateral portal and passed through the eyelet of a footprint anchor (Fig 14). After tightening the threads, the anchor is screwed in at the distal part of the greater tuberosity through the anterior lateral portal (Fig 15 and Video 1). If the anterior-to-posterior diameter of the tendon tear is larger than 2 mm, then another suture thread and anchor can be added in the same way.

Postoperative Rehabilitation

The patient is immobilized in a sling for 6 weeks. Passive range of shoulder motion begins 1 day after the surgery. Active-assisted motion begin 6 weeks postoperatively. Both passive and active shoulder abduction are avoided within 4 weeks postoperatively. Weight-bearing or strengthening exercises are allowed after 12 weeks.

Discussion

The goals of rotator cuff repair are to reduce pain and to restore shoulder function, which require anatomic footprint restoration with minimum gap formation, broad tendon-to-bone contact area, and biological stimulation to promote tendon−bone healing.[1-4] Theoretically, the standard suture bridge has many advantages over single- and double-row repair.[5-7] Clinically, the rotator cuff cannot be adequately mobilized and anatomic bone-to-tendon repair would be difficult because of excessive tension.[17-19] The surgeon should avoid passing medial row sutures too medial to predispose to type II failure of rotator cuff repair. Poor suture holding strength of the degenerated tendon tissue and strangulation of the

Table 2. Advantages and Disadvantage of This Technique

Advantages	Disadvantages
1. Without medial row anchor knot-tying, one can avoid tissue strangulation	1. Without medial row anchor knot tying, the torn tendon cannot obtain complete contact with the footprint during shoulder abduction in the early time postoperatively
2. Reduces stitch stimulating response under the subacromial space	2. BMS will damage bone bed if bone quality is poor
3. Torn tendon edge can be firmly pulled back to the footprint surface	3. Lack of long-term follow-up
4. Low risk of laceration or further damage on the tendon	
5. Prevents most of bone marrow cell extravasation far away from tendon bone surface after BMS	
6. Easy to learn	
7. Economic savings due to no medial row anchor	

BMS, bone marrow stimulation.

tissue due to knot-tying at the medial row have also been proposed as mechanisms explaining medial row failure in standard suture bridge.[8,20,21]

With this technique, the rotator cuff is repaired by 1 or 2 footprint anchors without a medial row anchor. The advantages are as follows: First, as a modified suture bridge, the medial row is performed only by suture threads in a modified Mason—Allen fashion without knot-tying to avoid tissue strangulation. Second, without knot-tying, it reduces stitch stimulating response under the subacromial space. Third, with modified Mason—Allen suture, the torn tendon edge can be firmly pull back to the footprint surface, with low risk of laceration or further damage on the tendon. Fourth, it is simple to perform, with a short learning curve and greatly economical for medical reimbursement.

Without a medial row anchor, the torn tendon cannot obtain complete contact with the footprint during shoulder abduction. To compensate for this disadvantage, we use BMS to promote the healing progress and avoid early shoulder abduction after surgery. To our knowledge, the clot that flows out through the bone marrow contains several kinds of elements, including mesenchymal stem cells, growth factors, and platelets, which are helpful to enhance early tendon healing.[13-15] Some studies have shown that the use of BMS reduces the retear rate in repaired rotator cuff significantly compared with other methods.[22,23] The "crimson duvet" was originally described to be performed away from the medial row anchor holes, as leaving the bone marrow vents uncovered permits the free flow of bone marrow.[16] Yoon et al.[24] proposed that the uncovered footprint may not maintain bone marrow droplets, which would subsequently vanish into the subacromial space. This technique pulls the rotator cuff tendon full cover the greater tuberosity by knotless suture bridge, which prevents most of bone marrow cells extravasation too far from tendon bone surface after BMS. Compared with the "crimson duvet," we believe the "Greenhouse" technique provides a better biological environment. Pearls and pitfalls and advantages and disadvantages are summarized in Tables 1 and 2, respectively.

In summary, the "Greenhouse" technique is a safe and easy technique for rotator cuff repair. It avoids the negative impact by the medial row anchor and incorporates BMS to promote healing. Further studies are warranted for the evaluation on tendon healing in the long term.

References

1. He HB, Hu Y, Li C, et al. Biomechanical comparison between single-row with triple-loaded suture anchor and suture-bridge double-row rotator cuff repair. *BMC Musculoskelet Disord* 2020;21:629.
2. Ansah-Twum J, Belk JW, Cannizzaro CK, et al. Knotted transosseous equivalent technique for rotator cuff repair shows superior biomechanical properties compared to a knotless technique: A systematic review and meta-analysis [published online ahead of print Oct 2, 2021]. *Arthroscopy*. https://doi.org/10.1016/j.arthro.2021.09.017.
3. Wu Z, Zhang C, Zhang P, Chen T, Chen S, Chen J. Biomechanical comparison of modified suture bridge using rip-stop versus traditional suture bridge for rotator cuff repair. *Biomed Res Int* 2016;2016:9872643.
4. Cole BJ, ElAttrache NS, Anbari A. Arthroscopic rotator cuff repairs: An anatomic and biomechanical rationale for different suture-anchor repair configurations. *Arthroscopy* 2007;23:662-669.
5. Neyton L, Godenèche A, Nové-Josserand L, Carrillon Y, Cléchet J, Hardy MB. Arthroscopic suture-bridge repair for small to medium size supraspinatus tear: Healing rate and retear pattern. *Arthroscopy* 2013;29:10-17.
6. Gartsman GM, Drake G, Edwards TB, et al. Ultrasound evaluation of arthroscopic full-thickness supraspinatus rotator cuff repair: Single-row versus double-row suture bridge (transosseous equivalent) fixation. Results of a prospective, randomized study. *J Shoulder Elbow Surg* 2013;22:1480-1487.
7. Behrens SB, Bruce B, Zonno AJ, Paller D, Green A. Initial fixation strength of transosseous-equivalent suture bridge rotator cuff repair is comparable with transosseous repair. *Am J Sports Med* 2012;40:133-140.
8. Cho NS, Lee BG, Rhee YG. Arthroscopic rotator cuff repair using a suture bridge technique: Is the repair integrity actually maintained? *Am J Sports Med* 2011;39:2108-2116.
9. Sun Y, Kwak JM, Kholinne E, Tan J, Koh KH, Jeon IH. Nonabsorbable suture knot on the tendon affects rotator cuff healing: A comparative study of the knots on tendon and bone in a rat model of rotator cuff tear. *Am J Sports Med* 2019;47:2809-2815.
10. Gerhardt C, Hug K, Pauly S, Marnitz T, Scheibel M. Arthroscopic single-row modified Mason-Allen repair versus double-row suture bridge reconstruction for supraspinatus tendon tears: A matched-pair analysis. *Am J Sports Med* 2012;40:2777-2785.
11. Yamakado K. Two techniques for treating medium-sized supraspinatus tears: The medially based single-row technique and the suture bridge technique. *JBJS Essent Surg Tech* 2021;11:e20.00004.
12. Dukan R, Ledinot P, Donadio J, Boyer P. Arthroscopic rotator cuff repair with a knotless suture bridge technique: Functional and radiological outcomes after a minimum follow-up of 5 years. *Arthroscopy* 2019;35:2003-2011.
13. Caplan AI. Adult mesenchymal stem cells for tissue engineering versus regenerative medicine. *J Cell Physiol* 2007;213:341-347.
14. Min BH, Truong MD, Song HK, et al. Development and efficacy testing of a "hollow awl" that leads to patent bone marrow channels and greater mesenchymal stem cell mobilization during bone marrow stimulation cartilage repair surgery. *Arthroscopy* 2017;33:2045-2051.
15. Kida Y, Morihara T, Matsuda K, et al. Bone marrow-derived cells from the footprint infiltrate into the repaired rotator cuff. *J Shoulder Elbow Surg* 2013;22:197-205.

16. Snyder SJ, Burns J. Rotator cuff healing and the bone marrow “Crimson Duvet ” from clinical observation to science. *Tech Shoulder Elbow Surg* 2009;10:130-137.
17. Yamakado K, Katsuo S, Mizuno K, Arakawa H, Hayashi S. Medial-row failure after arthroscopic double-row rotator cuff repair. *Arthroscopy* 2010;26:430-435.
18. Trantalis JN, Boorman RS, Pletsch K, Lo IK. Medial rotator cuff failure after arthroscopic double-row rotator cuff repair. *Arthroscopy* 2008;24:727-731.
19. Park SG, Shim BJ, Seok HG. How much will high tension adversely affect rotator cuff repair integrity? *Arthroscopy* 2019;35:2992-3000.
20. Kim YK, Jung KH, Won JS, Cho SH. Medialized repair for retracted rotator cuff tears. *J Shoulder Elbow Surg* 2017;26:1432-1440.
21. Kim YK, Moon SH, Cho SH. Treatment outcomes of single- versus double-row repair for larger than medium-sized rotator cuff tears: The effect of preoperative remnant tendon length. *Am J Sports Med* 2013;41:2270-2277.
22. Jo CH, Shin JS, Park IW, Kim H, Lee SY. Multiple channeling improves the structural integrity of rotator cuff repair. *Am J Sports Med* 2013;41:2650-2657.
23. Taniguchi N, Suenaga N, Oizumi N, et al. Bone marrow stimulation at the footprint of arthroscopic surface-holding repair advances cuff repair integrity. *J Shoulder Elbow Surg* 2015;24:860-866.
24. Yoon JP, Chung SW, Kim JY, et al. Outcomes of combined bone marrow stimulation and patch augmentation for massive rotator cuff tears. *Am J Sports Med* 2016;44:963-971.