Rotator Cuff Healing and the Bone Marrow
“Crimson Duvet” From Clinical Observations to Science

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Abstract: The goal of improving rotator cuff healing has been a high priority for orthopedic shoulder surgeons since Codman showed the feasibility of repair in 1909. Early efforts were directed toward improving surgical techniques to optimize the mechanical tendon fixation to bone. These efforts have been very successful and include improved sutures and bone anchors, less complicated suture passing and knot tying, better methods to relieve impingement and release tethered tendons, and advances in postoperative protection and rehabilitation. Despite these important advances, there continues to be a large percentage of cuff repairs that fail, leaving the patients with a less-than-optimal function. Recent researchers have reported re-rupture rates after open or arthroscopic rotator cuff repair of between 13% and 94%. Over the last 20 years, our shoulder team at Southern California Orthopedic Institute has repaired more than 3000 rotator cuff tendon tears using arthroscopic visualization, consistently fixing the tendon edge a few millimeters lateral to the supraspinatus footprint adjacent to the articular cartilage. We always use a single row of suture anchors with 2 and often 3 sutures per anchor in an effort to obtain the strongest possible repair with the least possible tension on the construct. In postoperative follow-up magnetic resonance imaging examinations, we commonly observe that the footprint of the rotator cuff completely regenerates to cover the greater tuberosity despite having been completely debrided of all soft tissues at the time of the repair. This paper examines the important contemporary knowledge of biologic factors relevant to the basic science of tendon healing and discusses a study evaluating dynamic blood flow imaging of the healing cuff using contrast ultrasound and magnetic resonance imaging, and presents several surgical biopsies. Finally, we present a simple method for guide cells, thereby encouraging migration and proliferation. Growth factors (small proteins) that are important for cuff healing are derived from degranulating platelets, serum, and local cells. In the normal injury response, these growth factors are provided by the body’s healing cascade both in the required amounts and at the appropriate times during the healing sequence. Cells are the important driving force for tissue healing and are considered the “metabolic engine” that powers the repair. The origin of appropriate cells for repair in tendon healing is predominantly from the pluripotent cells from adjacent tissues, most importantly the “super clot” from the bone marrow. (Ref. Uthoff 12 and 14) The sequence of repair begins with the inflammatory phase in which cells are recruited to an area by chemotactic growth factors. At the appropriate time, mitogenic growth factors then stimulate cellular and vascular proliferation to lay down the collagen framework and restore the critical blood supply. Tissue formation proceeds in an orderly sequence driven by both biologic and physical factors in interacting and guiding the local cell phenotype (pluripotential cells or stem cells) and local environmental factors. Tissue remodeling and maturation is the final phase of the healing process. During this phase the repaired tissue is turned over or remodeled, leading to the optimal structure for the required functional demands.

In normal, healthy tissue, the biologic healing response cannot be hastened, it can only be “optimized.” In a degenerative or biologically compromised rotator cuff, the normal sequence of healing may be diminished, and it may be useful to introduce additional stimuli. In a condition of suboptimal tissue quality, such as a chronically torn or degenerative rotator cuff, there will likely be a deficiency of growth factors as a result of an inadequate vascularity and thereby clot formation. This will result in a deficiency of platelets, and thus a diminution in both concentration and duration of growth factors. The result will be the failure to incite cell and vascular migration for both inflammation and matrix development. Supplying additional growth factors, stem cells and blood flow in this situation may likely contribute the important missing raw materials to improve chances of healing.

DEFINITION OF CRIMSON DUVET

The term, “Crimson duvet” describes a reddish purple (crimson) colored clot that issues forth from small “bone marrow vents” punctured in the cortex of the greater tuberosity during rotator cuff repair surgery. The perforations must enter the cancellous bone thereby allowing the bone marrow to flow out to cover the denuded tendon as well as the repaired rotator cuff tendon. The resulting clot resembles a blanket (duvet). This “super clot” is known to contain a rich cache of mesenchymal stem cells (MSCs), platelets with their growth factors and vascular elements, and vascular access channels, all of which will contribute to cuff healing.

“The recipe for the normal healing response of connective tissue is an exquisitely designed continuum of events that are interdependent and subject to both intrinsic and extrinsic signaling,” according to Steven P. Arnoczky, DVM (“Biologic Adjuncts to Connective Tissues Healing,” presented at the Arthroscopy Association of North America Specialty Day, Las Vegas, Nevada, February 2009).

According to Dr Arnoczky, the healing response requires access to a rich supply of blood. The blood provides polymorphonuclear cell, macrophages, a fibrin clot (temporary scaffold), and a reservoir for growth factors with platelets trapped in the clot. The scaffold also provides a conducive surface to guide cells, thereby encouraging migration and proliferation.

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Clinical Impressions Leading to Understanding the Function of Bone Marrow Clot and the Crimson Duvet

Sequential Magnetic Resonance Imaging

The development and maturation of the Crimson duvet was first appreciated by observing the sequential magnetic resonance imaging (MRI) scans performed every few weeks postoperatively to determine the course of healing. The patient was a 53-year-old radiologist with a 2.5 cm rotator cuff tear repaired with 2 triple-loaded suture anchors. He volunteered to have sequential MRI scans postoperatively to follow cuff healing. His preoperative scan documented a large full-thickness tear including the supra and infraspinatus attachments with minimal retraction (Fig. 1). At surgery, the tuberosity was debrided and small bone marrow vents were created. The cuff edge was attached just lateral to the cartilage using 2 triple-loaded suture anchors and simple sutures. The first postoperative scan was performed at 4 weeks. The cuff edge appeared well fixed to the edge of the cartilage and there was a moderate bursal effusion but there was not soft tissue over the tuberosity. At 6 weeks, the effusion was resolving but the tuberosity was still bare. At 8 weeks a soft tissue signal (footprint) was evident covering the entire tuberosity. In the ensuing months the new “footprint” became increasingly more dense and by 3 months had the MRI appearance of a relatively normal rotator cuff attachment. A scan performed 2 years postoperatively revealed that the cuff attachment was robust and sound.

Since this interesting sequence, we have had occasion to evaluate several hundred postoperative MRI scans and have noted that by and large the footprint area of the rotator cuff has been completely restored when we have debrided the remaining torn cuff, abraded the bone, and created bone marrow vents facilitating the formation of the Crimson duvet.

Second Look at Cases With Early, Mid, and Late Visual Evaluation

There were also several observations made during the “second look” arthroscopic evaluations. On one occasion, a patient had a suspected infection at 2 weeks postoperatively and was taken to surgery for an arthroscopic evaluation and lavage and debridement. The evaluation documented that the earlier bare tuberosity was covered with a rich vascular blanket covering and nearly obscuring the cuff edge and suture line (Fig. 2).

A second case example was that a 52-year-old female who was involved in a motor vehicle accident 4 weeks postoperatively and in a 2-anchor rotator cuff repair. She had bleeding in her bursa and the MRI suggested that she had torn part of her cuff repair but the adjacent area was healing well (Fig. 3). Her redo cuff repair at 8 weeks documented that the entire tuberosity was covered with a healthy looking tissue (Fig. 4). When it was debrided, the previously placed bone marrow vents had robust cores of fibrovascular tissue connected to the overlying Crimson duvet (Fig. 5).

Opportunistic Biopsies of Tissue on Tuberosity

Finally, there were 2 opportunities for a biopsy of the healing Crimson duvet. The first was a 40-year-old male who had a “seroma” at 5 weeks postoperation. The MRI was worrisome but the arthroscopic evaluation and cultures ruled out infection. Biopsies were taken from the soft tissue covering the tuberosity area that had been prepared earlier with abrasion and bone marrow vents. The micropathology showed a rich fibrin matrix infiltrated with healthy fibroblasts and lymphocytes and an abundant array of vascular elements. There were no inflammatory cells present (Fig. 6).

The second case was a 46-year-old male who had a rotator cuff repair but partially re-tore the tendon 3 months later...
playing in a golf tournament. The biopsies were taken at 3 years in the area of the rotator cuff footprint, which had been the site of the previous bone marrow vents during the cuff repair. The biopsy specimen revealed normal appearing rotator cuff tendon attachment. The typical tidemark was present and fibrocartilage and bone interdigitations were evident (Fig. 7).

MRI Case Studies
In addition, we have collected more than 100 cases all of whom had a single row rotator cuff repair adjacent to the articular cartilage and have undergone postoperative MRI imaging at various times after surgery. Although most cases have healed well, even those that failed still showed regrowth of soft tissues resembling a “footprint” on the rotator cuff attachment site (Figs. 8, 9).

Surgical Techniques to Maximize Development of Crimson Duvet
The technique of creating a Crimson duvet is simple. The soft tissue remnants of bursa and rotator cuff tissue on the humerus are debrided from the edge of the articular cartilage 2 to 3 cm lateral on greater tuberosity. The cortical bone is preserved at the edge of the cartilage to insure good anchor fixation but is superficially abraded laterally from that area. Multiple 1.5 mm puncture holes (bone marrow vents or microfractures) are created in the tuberosity bone using a bone punch or awl (Fig. 10). The vents are placed 3 mm apart and angled down the shaft of the humerus away from the anchor holes. Care must be taken to avoid fracture of the tuberosity. The cuff edge is attached near the edge of the articular cartilage taking care to insert the anchors in a 30 to 45 degrees medial angle under the subchondral bone for best fixation. This medial footprint attachment will insure that the joint is sealed and with the least possible tension on the repair site while also avoiding covering the bone puncture sites with the lateralized cuff. Covering the sites will prevent marrow egress from having access to the important bursal side of the tendon, likely hampering bridging of the tissue from bone to bursal surface. When the surgery is completed and the fluid

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**FIGURE 2.** The “Crimson duvet” is well established at 2 weeks postoperation covering the tuberosity and extending over the cuff and suture line.

**FIGURE 4.** Arthroscopy at 8 weeks showed that the “Crimson duvet” completely covered the tuberosity and the entire cuff except for a small area around the anterior suture anchor.

**FIGURE 3.** This patient had an motor vehicle accident at 4 weeks postoperation and re-tore her rotator cuff repair. The magnetic resonance imaging at 8 weeks shows the injured area lateral to the anterior anchor and another portion of the cuff that remained intact adjacent to the posterior anchor.

**FIGURE 5.** After debridement of the “Crimson duvet” lateral to the anterior anchor the previously placed “bone marrow vents” could be seen filled with a rich fibrovascular core of tissue. The area of the tuberosity that had been abraded but without “Vents” did not have significant soft tissue attached.
When the pump is turned off, bone marrow will flow from the vents and form the Crimson duvet covering the rotator cuff (Figs. 11, 12).

**DISCUSSION**

Study of the basic principles of bone fracture healing has revealed the importance of the callus/clot to the local healing response. A fracture disrupts blood vessels within and around the bone, setting off a series of events that progress over several stages from hematoma to mature remodeled bone tissue. Similarly, creation of a Crimson duvet in the shoulder accesses this same healing process and directs it to the damaged rotator cuff tissue.

In rotator cuff repair, when the small bone vents “fracture” the greater tuberosity, the first response is the creation of a marrow-generated hematoma. As vessels within the bone bleed, marrow cells also egress, and a clot forms adjacent to the rotator cuff-bone interface. This hematoma creation is the first of several discrete stages of bony healing. Fracture clots with degranulating platelets are the source of the signaling molecules such as transforming growth factor-β and platelet-derived growth factor, which not only regulate the proliferation of cells but also regulate the differentiation of committed MSCs into more mature functional cells suited to their environment, that is, fibroblasts. In fact, these are just 2 of many such “signaling molecules” within a fracture clot, the majority of which are still poorly understood. As the signals are sent, inflammatory cells arrive and secrete vital cytokines such as interleukins 1 and 6, factors that also support tissue neoangiogenesis. In true fracture settings, this system will continue, creating and remodeling bone back to bone. In the damaged local environment of a rotator cuff tear, this regenerative process of cell signaling, proliferation, differentiation, and vascularization is also crucial when bone-to-tendon healing is to be achieved.

**Microfracture and Formation of “Super Clot” for Cartilage Regeneration**

According to Steadman et al., full-thickness articular cartilage defects rarely heal spontaneously and most chondral defects most often eventually cause degenerative changes. Other than joint replacement, techniques to treat full-thickness chondral defects include drilling abrasion, autografts, allografts, and cell transplantation. Dr Richard Steadman developed the technique for microfracture to enhance chondral resurfacing by providing a suitable environment for new tissue formation and taking advantage of the body’s own healing potential. Variable angle, sharp-tip metal awls are used to make multiple perforations into the subchondral bone plate.
The perforations are usually made approximately 3 to 4 mm apart. The integrity of the subchondral bone plate must be maintained. The released marrow elements (including MSCs, growth factors, and other healing proteins) form a surgically induced super clot that provides an enriched environment for new tissue formation. The proper rehabilitation protocol is critical. It is designed to promote the ideal physical environment for the marrow stem cells to differentiate into articular cartilage-like cells, ultimately leading to the development of a durable repair cartilage that fills the original defect.

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The theory behind the development of microfracture for cartilage injury in the knee is based on the same principles of fracture healing and the cuff repair discussed above. Creating small holes in the defect in the femoral condyle, accessing healing elements from the marrow to fill the defect, and giving them time to regenerate has shown clinical and histologic improvements in several follow-up studies.\(^7\)–\(^10\) This technique has become an important part of most knee surgeons' armamentarium. Although the quality of the regenerated cartilage is still a matter of debate, microfracture site biopsy has shown the procedure to reliably improve the damaged environment by creating new regenerative tissue from the marrow elements.

**Rotator Cuff Healing With Bone Marrow Cells**

Hans K. Uthoff and Guy Trudel have studied rotator cuff healing for several decades. Their research and teaching have focused on the biologic nature of tendon-to-bone healing rather than mechanical factors. Their investigations show that degenerative rotator cuff insertions are composed of irregular collagen bundles, granulation tissue, and calcifications. This area is designated the "enthesis" and is the location of eventual tears.\(^1\)–\(^12\) The torn tendon edge is an unfavorable environment for cellular proliferation and vascular invasion. In addition to unorganized collagen bundles, it is often surrounded by a catabolic environment including matrix metalloproteinases and giant cells.\(^3\)–\(^13\),\(^14\) Clearly, the atrophic tendon is nearly incapable of healing without intervention. Stable fixation...
remains only 1 piece of the puzzle as bridging fibrocartilage is unlikely to form if degenerative tendon is compressed against sclerotic tuberosity. Uthloff proposes maximizing healing potential by preserving bursal tissue and releasing bone marrow stem cells from tuberosity. In the bursa, vascular invasion and fibroblast proliferation appear to aid healing as seen in the histologic analysis of a rabbit model and human specimens. Similar analysis proves that exposure of subcuticular bone allows an influx of fibroblasts and vessels leading to a fibrocartilaginous bridge to the tendon stumps. In addition to exposed cancellous bone, venting the bone marrow would allow an influx of stem cells to magnify the vascular and fibrocartilage response. Timing to fixation may also play a role as the work by Matsumoto, Zumstein, Gladstone and Gerber illustrates that muscle atrophy is not reversed after fixation and often progresses. In essence, a timely, biomechanically sound repair of the rotator cuff that exploits the biologic benefits of the subcuticular bone, that is, bone marrow stem cells, should lead to improved healing and a superior clinical result according to Uthloff’s study.

**Histology of Cuff Tendon Repair**

Christian Gerber was the first to evaluate the histology of the rotator cuff tendon repair by establishing the first animal model for cuff repair research, the Alpine sheep. The infraspinatus tendon of this sheep is similar to the human supraspinatus. As he was developing the model for new suture constructs for repair, he studied the histology of sheep infraspinatus tendon repair to bone. Like Uthloff’s study in rabbits, Gerber also found the tendon stump to initially have decreased vascularity and reduced numbers of fibrocytes, although this began to improve after 2 weeks. By 6 weeks, fibroblasts and vessels were present in large numbers. In fact, at the tendon-bone junction, vessels extend from the bone marrow into the scar tissue, indicating healing from the tuberosity. By 6 months, the granulation tissue developed into tissue with parallel-oriented collagen fibers, whereas osteoblasts formed a new bone mass embedding the fibers, with a layer of dense fibrocartilage covering it, as it does in the normal tendon-bone interface.

**Tuberosity and Rotator Cuff Blood Flow**

In a clinical study conducted at the Hospital for Special Surgery, the investigators documented that the important blood supply for rotator cuff healing did originate from the greater tuberosity bone and not from the cuff tendon. They evaluated 13 patients each having undergone a single row arthroscopic rotator cuff repair. At 3 months postoperation, they quantified in vivo vascularity of the rotator cuff and the surrounding area using lipid microsphere-enhanced ultrasound evaluation. The conclusion of their study was that the rotator cuff is relatively avascular after repair at 3 months, a robust vascular response occurs at the suture anchor site in the greater tuberosity, and that an intact repair may be necessary to foster angiogenesis at the repair site. The data suggest that the repaired rotator cuff tendon is relatively avascular and that the blood supply to the tendon-bone interface comes from the tuberosity.

**Muscle Atrophy, Fat Infiltrate, and Cuff Tension**

Dr Christian Gerber has also used a sheep model to evaluate the effect of chronic tear on the infraspinatus muscle belly. Histologic analysis shows that as the muscle fibers atrophy, fat and connective tissue then infiltrate the interfascicular and intrafascicular spaces left behind, leading to increased stiffness of the musculotendinous unit. Tension measurements for 1 and 2 cm excursion were taken at the time of initial tendon release and compared with the measurement taken 40 weeks later at the time repair was performed. The tension increased over 7-fold for 1 cm excursion. After 40 weeks, the musculotendinous unit was so stiff that it could no longer be mobilized at 2 cm.

Human in vivo data also show the significant difference in tension in medially based single row versus double row repair constructs. A tensiometer was used to measure the tension of the cuff musculotendinous unit when the edge was reduced to the articular margin and the lateral footprint of greater tuberosity. The average force required to bring the edge of a small tear (<20 mm) to the margin was 1.25 N compared with 9.08 N for lateral tuberosity. Tears that retracted >20 mm required 3 N to the margin and 13.75 N to the lateral tuberosity. The amount of retraction of the tendon in combination with the inelasticity of a chronic tear can lead to excessively high-tension repairs, which may be a setup for nonhealing. A lower-tension medially based repair construct in combination with the released MSCs and growth factors in the Crimson duvet may give the tendon the most optimal environment in which to heal.

**Bone Marrow Cell Concentrations in the Humeral Greater Tuberosity**

Bradley et al studied the composition of bone marrow aspirate (BMA) from the proximal humerus to determine the composition and feasibility as a handy source for the harvest of MSCs to aid rotator cuff healing. They noted that earlier work has been limited to characterization of cellular components in BMA from the iliac crest and vertebral body. An earlier clinical study used MRI to identify hematopoietic marrow in the humerus of 99% of patients aged 13 to 83 years old, but the cellular make-up or the amount of stem cells in humeral bone marrow was not evaluated. Bradley et al postulated that if the humerus provides a source of stem cells to aid in tissue repair, then obtaining BMA during shoulder arthroscopy would become a relatively simple and convenient procedure to aid the repair process. Their study included 12 male and female patients aged 21 to 75 years undergoing rotator cuff repair or shoulder instability repair. Approximately 10 mL of bone marrow was aspirated into a syringe with 100 U/mL of heparin from the humeral metaphysis of each patient through the greater tuberosity. The BMA was processed at UPMC Hillman Center. The results of the aspirates were compared with investigations published earlier quantifying progenitor cells in BMA from the iliac crest. There were 518 ± 707 MSCs/mL, of humeral BMA. These numbers are compared with Muschler’s publication in which he reported 301 colony-forming units /mL of iliac crest BMA. MSCs and colony-forming units are essentially the same term according to Bradley. They conclude that a similar amount of connective tissue progenitor cells can be obtained from the humerus as the iliac crest. It is noted that the standard deviations of ESCs and MSCs are larger than the values themselves. It is likely that there are differences in the amount of progenitor cells found in each individual patient’s bone marrow, especially because of age.

**Growth Factors Enhancement From Acromial Cancellous Bone**

The presence of high levels of growth factors following opening of the cancellous bone in the acromion was shown by...
Randelli et al. Thirty-two patients were involved and fluid was collected from the subacromial space postoperation using a suction drain. This fluid was compared with a sample of peripheral venous blood taken at the same time. The samples were compared for concentrations of growth factors using enzyme-linked immunosorbent assay. Platelet-derived growth factor-AB, fibroblast growth factor basic, and transforming growth factor-β1 were all significantly higher in the subacromial fluid than in the blood. This suggests that opening the cancellous bone of the acromion as well as the tuberosity releases a significant quantity of growth factors into the subacromial environment. It is expected that these growth factors will potentiate the healing of the repaired rotator cuff.

CONCLUSIONS

The information presented in this paper is a compilation of observations, impressions, surgical case reviews, literature, and scientific data gleaned by the authors over more than 20 years performing arthroscopic rotator cuff repair techniques. During this time we have witnessed many new and creative concepts evolve that were designed to enhance and improve cuff healing. Biologic repair of all living tissues consistently requires 5 key elements: stabilization, inflammation, revascularization, cellular repopulation, and remodeling. We must understand and respect these principles. The unacceptably high numbers of failed repairs noted in the literature for both using arthroscopic and open cuff techniques demands that we pursue better methods that improve our patient’s outcomes. It is evident that we need to study, understand, and learn to take advantage of the body’s natural healing potential. All too often, a new and often more expensive technology is touted to be a revolution in surgical care only to be abandoned when it is shown to be little more than a different surgical exercise. The simple and predictable concept of puncturing small holes or bone marrow vents in the prepared tuberosity, fixing the cuff securely with minimal tension, and facilitating the bone marrow to flow and cover the repaired cuff forming a healing blanket or Crimson duvet seems to be the best current method we know to achieve this goal. No doubt the future will include additional methods to enhance and support healing but until they are proven and available we should do our best to provide the best possible biologic environment for the cuff to heal and avoid unnecessary additional surgical trauma.

REFERENCES


29. Kevy S. Trans 52nd Annual ORS Meeting, 2006; Paper No. 1738.