Early Results Using a Dynamic Method for Delayed Primary Closure of Fasciotomy Wounds

Rebecca C Taylor, BSc, MD, Bert J Reitsma, MD, PhD, Sue Sarazin, RN, ET, Michael G Bell, MD, FRCS, FACS

Fasciotomy incisions, which are usually performed for compartment syndrome, cannot be closed primarily because of excessive tension across the wound secondary to postischemic swelling of the extremity. Split-thickness skin grafting, the conventional method of fasciotomy closure, is effective but it results in an insensate and cosmetically unappealing wound and is associated with donor site morbidity.[1,2]

Skin has several unique and useful properties that allow for delayed primary closure of wounds despite large tissue defects or significant retraction. These biomechanical properties, which include inherent extensibility and mechanical and biological creep, have been exploited by a variety of techniques for delayed primary closure of fasciotomy wounds. The vessel loop shoelace technique,[3,4] use of the Sure-Closure skin-stretching device (Comesa),[5-10] use of a prepositioned cutaneous suture,[11-14] and several other techniques[15-17] have shown reasonable wound closure rates and wound cosmesis, but have been criticized because they are expensive, cumbersome to apply and to tighten,[6] or are associated with increased compartment pressures[9,10,14] and skin edge necrosis.[5,6,18,19]

The following case series presents our results using a new method of dynamic wound closure with a novel device (Canica Design, Inc) applied to six fasciotomy incisions.

TECHNIQUE

Five patients underwent six fasciotomy incisions between December 1999 and September 2001 at our institution. A dynamic method of wound closure was applied by a single plastic surgeon (MB) who also

performed followup. The surgical technique is briefly described, followed by the case reports.

The technique involves application of skin anchors approximately 1 cm back from the wound margins. Two different skin anchor designs were used in our series (Fig. 1). The cleated skin anchor has two small front cleats that penetrate the skin surface through two small incisions and the skin anchor can then be sutured or stapled. This was performed at the bedside under local anesthesia. The adhesive skin anchor lacks these front cleats and is firmly attached to a piece of adhesive hydrocolloid base. It is applied to the wound margin by sticking the adhesive surface to the skin similar to the application of a colostomy apparatus to the anterior abdominal wall. The adhesive skin anchors are less invasive but also less durable and they are therefore best suited when the duration of closure is estimated to be less than 2 weeks. A silicone elastomer (12F) is then laced across from one skin anchor to the next in a running fashion or multiple elastomers can be attached to opposing anchors. The first method is preferred when even tension across the wound is desired for the entire length of the wound and when the skin is thin and fragile; the second method is useful when different closing forces are required at different points along the wound.

The open wound is dressed with normal saline-soaked gauze or any moist dressing cut to the wound size and positioned under the elastomers. The elastomers can be tightened every 1 to 3 days as convenient by the surgeon or by a nurse trained in wound care. Tightening is undertaken by unfastening the elastomer on one side of the wound, pulling the excess length through the anchor, and refastening. The elastomer should be tightened until there is no laxity in the skin edges; usually this corresponds to approximately 50% to 75% of the elastomer stretch limit. If the patient experiences more than mild discomfort after tightening, the elastomers should be loosened until the discomfort subsides. Once skin apposition is achieved, the wound can be closed with sutures or adhesive strips or the dynamic closure apparatus can be left in place until adequate skin adhesion has
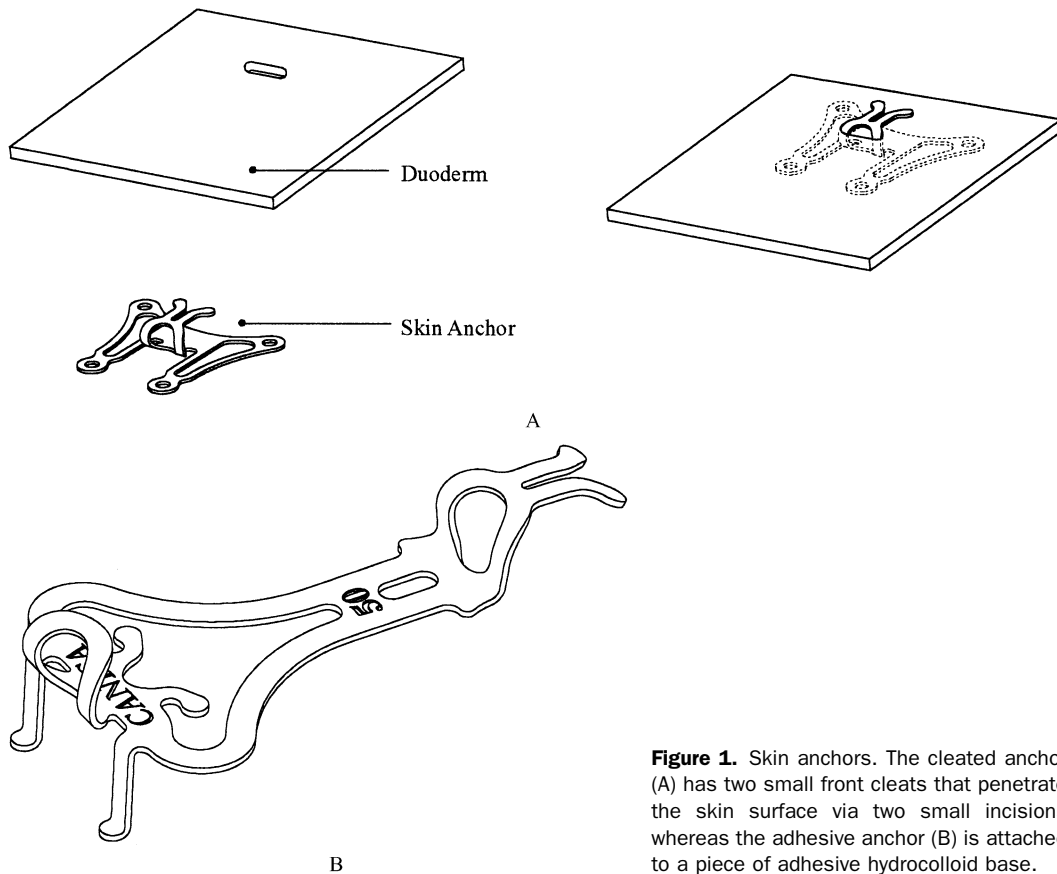
Figure 1. Skin anchors. The cleated anchor (A) has two small front cleats that penetrate the skin surface via two small incisions whereas the adhesive anchor (B) is attached to a piece of adhesive hydrocolloid base.

formed. Throughout application of the system, patients are encouraged to maintain a full range of motion and weight bear as appropriate.

At present, the dynamic closure apparatus used in these cases is approved as a category 1 medical device by Health Canada and by the Ottawa Hospital Research Ethics Review Board for investigational use in the primary closure of fasciotomy incisions. It has been commercially available in Canada since December 2002.

PATIENTS
Patient 1
A 54-year-old woman developed a compartment syndrome from an ischemic left lower leg after a total knee replacement complicated by a popliteal artery laceration. She underwent a medial and lateral fasciotomy of the lower limb. Her postoperative course was complicated by respiratory and renal failure requiring admission to the intensive care unit. The plastic surgeon was consulted on postoperative day 10, and the cleated dynamic wound closure method was applied to both incisions under local anesthesia. The wounds were approximated at 14 days and the skin anchors were removed at 4 weeks. No secondary suturing was required.

Patient 2
A 28-year-old man was shot and sustained a compound fracture to the left humerus and disruption of the brachial artery. The limb was ischemic for 18 hours during transport and a single fasciotomy incision was performed during an operation for fixation of the distal humeral fracture and brachial artery bypass. An attempt was made to close the fasciotomy defect using the vessel loop shoelace technique, but this was not successful and the plastic surgeon was consulted on postoperative day 21 for split-thickness skin grafting. The cleated dynamic wound closure method was applied instead; the wound was approximated in 10 days and was closed at that time with a monofilament suture (Fig. 2).

Patient 3
A 37-year-old man who underwent repair of a pseudo-aneurysm of the distal aortic arch with a femoral-to–

Figure 2. A 28-year-old man had an ischemic limb for 18 hours. An attempt was made to close the fasciotomy defect using the vessel loop shoelace technique (A), but this was unsuccessful. The cleated dynamic wound closure method was applied (B) and the wound was approximated in 10 days. The final result seen in clinic at 2 weeks (C).

femoral artery bypass developed a left peroneal compartment syndrome on postoperative day 1 requiring a

fasciotomy. At the time of fasciotomy, nylon vertical mattress sutures were left in place but not tightened to allow for a delayed primary closure. On postoperative day 5 an attempt was made to close the fasciotomy incision; this failed because the skin tension was excessive and the wound margins could not be approximated. The plastic surgeon was consulted at this time and the cleated dynamic wound closure method was applied. The wound margins were approximated in 13 days, during which time the patient remained fully mobile. The wound was sutured with a monofilament suture before the patient was transferred to a peripheral hospital because followup was not guaranteed.

Patient 4
An 83-year-old woman underwent an urgent brachial artery embolectomy and lower arm fasciotomy for compartment syndrome secondary to ischemia. The plastic surgeon was consulted on postoperative day 6, and the adhesive dynamic wound closure method was applied. The wound was approximated in 6 days and adhesive strips were subsequently applied to prevent elastic relapse of the skin margins.

Patient 5
A 38-year-old man developed a compartment syndrome after an open left radial and ulnar fracture sustained in a sand and gravel conveyer. The patient underwent an incision and drainage of the left forearm and a fasciotomy, followed 2 days later by an open reduction and internal fixation. The plastic surgeon was consulted on postoperative day 6 and the adhesive dynamic wound closure method was applied. The patient was discharged home with the closure system in place under the supervision of a homecare nurse. The wound was approximated in 12 days and was closed in the clinic using a monofilament suture (Fig. 3).

RESULTS
All six fasciotomy incisions were indicated for compartment syndrome. Three incisions were performed in the upper extremity and three in the lower extremity. The average length of fasciotomy incisions was 28.0 cm (range 17 to 34 cm) and the average width at presentation was 8.5 cm (range 6 to 12 cm) at its greatest dimensions. The average time from fasciotomy to application of the dynamic wound closure method was 9.8 days (range 6 to 21 days). In two patients, a previous attempt

at delayed primary wound closure had failed. The average number of days from application to wound approximation was 11.5 days (range 6 to 14 days) with a rate of closure of 1 cm per day. The average number of elastomer adjustments performed per patient was 4.67. Full range of motion was maintained for the involved limbs throughout the time required for closure. All six fasciotomy incisions were successfully closed with no need for a split-thickness skin graft and no complications of wound infection or skin edge necrosis. All five patients reported being satisfied with the cosmetic result of their fasciotomy wound closure.

DISCUSSION

Delayed primary closure is preferred over split thickness skin grafting for fasciotomy wounds because it is cosmetically and functionally superior. Skin has several unique biomechanical and physiologic properties that contribute to the success of delayed primary closure; the dynamic wound closure method makes use of these properties.

The term *inherent extensibility* describes the elastic property of skin. This property determines the amount of skin that can be safely excised while still obtaining an immediate primary closure, and it is estimated by pinching the skin.[20] Several investigators have described a technique in which sutures are placed at the time of fasciotomy and tied once the swelling in the limb has resolved.[11,12,14] This technique is successful for fasciotomy wounds that can be approximated under minimal tension, but will fail when used for wounds in which the skin cannot be approximated despite maximal force applied to the suture. This is exemplified in the case of patient 3 in whom prepositioned sutures failed to allow delayed primary closure. These wounds exceed the inherent extensibility of the surrounding skin.

The term *mechanical creep* denotes a biomechanical property of skin that allows it to gradually stretch beyond the limits of inherent extensibility. When a constant load is applied to an area of skin, that skin increases in length over time and subsequently the force required to keep it at this length decreases over time.[18] Gibson and Kenedi[19] and Gibson[21] have shown that this increase in length occurs within minutes and is explained by the predictable arrangement of collagen fibers in the skin. In the relaxed state, the collagen fibers are arranged in a randomly oriented pattern. As a load is applied to skin, the collagen fibers straighten longitudinally, aligning in
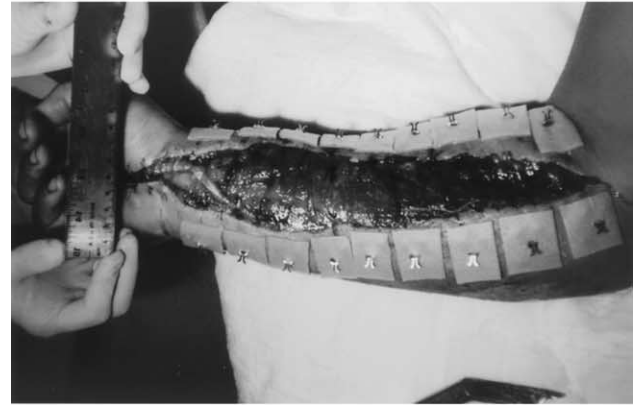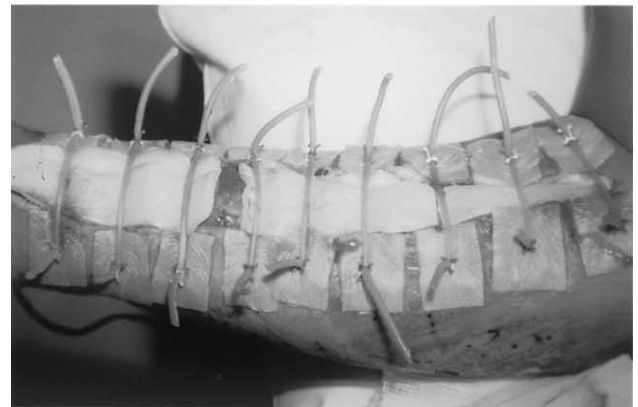
Figure 3. A 38-year-old man sustained a radial and ulnar forearm fracture requiring fasciotomy. The adhesive dynamic wound closure method was applied on postoperative day 6 (A) and the patient was discharged home with the closure system in place (B). The wound was approximated in 12 days and was closed in the clinic using a monofilament suture (C).

the direction of the stretching force, until the fibers are parallel and resist further extension. There is, however, a

finite limit to the extension that can be achieved by mechanical creep.

The Sure-Closure skin-stretching device applies the property of mechanical creep to facilitate delayed wound closure. This system consists of two pins that are threaded through the dermis of the wound margins, two U-shaped arms with hooks that engage the pins, and a screw that is threaded through the arms and turned to apply tension. The device is usually applied intraoperatively[5,6,9] and the skin is stretched to a predetermined tension (measured across the wound by the device) or until the skin blanches or becomes taut and shiny.[5] This procedure can be repeated at 10-minute intervals to enhance further the gain in skin length, a principle known as load cycling.[5,18] Although the device can measure the tension across the wound edges, this is not a guarantee of safety. Oxygen tension at the skin edges during stretching has been shown to decrease reversibly to 75% for 20 seconds; if the stretching is excessive, the small blood vessels in the skin are made taut with subsequent reduction or cessation of blood flow.[5] The collagen fibers can be overstretched, which results in their breakage.[5] Excessive force can lead to complications, including skin edge necrosis,[5,6] delayed healing, failure of wound closure,[22] recurrent compartment syndrome,[9,10,14] or longterm sequelae of hypertrophic scarring.[8] It is important to recognize that mechanical creep reaches an endpoint beyond which further stretching is counterproductive; appreciation of this end-point requires surgical experience.[5,6]

The Sure-Closure device has been criticized in the literature because it is expensive and limited in its application. Each device costs between $300 and $500 in United States dollars.[9,13] The devices are available in three sizes; the largest device cannot be applied to wounds greater than 7 cm in width.[13] This would preclude the use of this device in three of the six fasciotomy wounds reported here. If wounds are greater than 12 cm in length, several devices need to be applied sequentially, further increasing the cost.

The term *biological creep* denotes a physiologic property of skin that results in the generation of new tissue secondary to a persistent chronic stretching force, such as that which occurs in the gravid abdomen during pregnancy or during conventional tissue expansion.[23] Microscopically, there is a net gain of tissue that results from mitosis of fibroblasts, new collagen synthesis, and angiogenesis.[24] It is speculated that tensile factors stimulate this biosynthetic and mitotic activity of fibroblasts.[25] These histologic changes are unique to biological creep and are not found with intraoperative skin stretching.[26] Using a rat model, Lew and Fuseler[27] noted that within 48 hours there was an increase in the mitotic activity of the expanded skin that was 2.7-fold greater than that of the control skin. Beauchene and colleagues[25] also demonstrated a significant increase in the hydroxyproline content of the epidermis in rats 16 days after insertion of a peritoneal tissue expander. Other animal models, including those in the pig[28] and mouse,[29] have demonstrated similar results with a net gain of collagen and an increase in the mitotic index of fibroblasts seen within days of skin stretching. In 20 women undergoing breast reconstruction, a significant increase in the number of proliferating basal keratinocytes was demonstrated from biopsy specimens taken 1 day after insertion of a tissue expander as compared with specimens taken before insertion.[30] The property of biological creep allows skin to expand to almost limitless proportions.

The dynamic wound closure method described here and the vessel loop shoelace technique both take advantage not only of the biomechanical properties of inherent extensibility and mechanical creep, but also of the physiologic property of biological creep. These techniques are superior to others for large wound defects or wounds that would require excessive tension for closure. Both systems can be applied at the time of fasciotomy or shortly afterward, which has several advantages. First, the early mild tension exerted on the wound edges helps to increase the tissue hydrostatic pressure and facilitates the resolution of edema that occurs after compartment syndrome.[13] Second, both systems are dynamic, which allows a nearly constant closure force to be exerted over several centimeters of wound margin movement. This increases the safety and comfort of the apparatus and allows for early range of motion. Third, the dynamic wound closure avoids excessive forces across the wound because the stretching occurs gradually over days, allowing for the realignment of collagen and the generation of new tissue. Because the patients are awake during the tightening they are able to indicate whether the tension is excessive and painful. Skin blanching and patient discomfort are clear indicators that tension is excessive and are not therapeutic endpoints. Because the closure is not intended to be immediate, there is minimal concern about recurrent compartment syndrome or skin edge necrosis.

In contrast to vessel loops, which are difficult to tighten, this dynamic closure method is simple to use and can be adjusted daily. Dressing changes, which can be cumbersome with vessel loops, are not hindered by this method. The wound can be cared for with the system in place and the apparatus is durable enough to allow full range of motion and weight bearing. One of our patients went home with the system in place and was followed by a homecare nurse. He returned to the clinic within a week for definitive closure. This is a definite advantage over the vessel loop technique, which in our experience has limited tensile strength and is not durable.

The vessel loop was not designed for wound closure and lacks the force needed to close a large defect and the elasticity to permit stretch with wound movement. The vessel loop technique also exhibits point loading at the staple insertion sites because of excessive pull force, which can result in marginal ischemia on either side of the wound. The anchors used with the dynamic wound closure method are placed 1 cm away from the wound edge to prevent circulatory compromise at the skin edge by allowing for an evenly distributed push force over the full length of the wound. Point loading on the staples used in the vessel loop technique also leads to failure because they become dislodged with full range of motion or with tightening. Taken as a whole, the vessel loop technique applies the correct concept but with the wrong apparatus.

The dynamic closure method can be applied at the bedside and is useful for wounds that are identified as difficult only several days after fasciotomy when delayed suturing fails. It is our experience that a difficult wound is not always appreciated at the time of fasciotomy. In our six cases, the average time between fasciotomy and a plastic surgery consultation for assistance with wound closure was 10 days. The dynamic closure method avoids a second operation that is often required for application of the Sure-Closure device. In our opinion, delays in application of the wound closure apparatus such as those seen in this study are frequent and regrettable. The apparatus should ideally be applied at the time of fasciotomy and tightened as the swelling resolves. This will shorten the time between fasciotomy, wound closure, and discharge.

The dynamic closure apparatus can be applied to wounds of any width and dimension because it consists of separate components, including anchors that can be positioned in any way around the wound perimeter to maximize closing forces. We have used the apparatus on complicated wounds, including open sternal wound defects secondary to infection after open heart surgery, large open abdominal wounds resulting from enterocutaneous fistulae, and a skin defect secondary to necrotizing fasciitis. Our experience using this apparatus for these difficult wounds, although limited, is favorable so far because wound management is less demanding for the nursing staff, early mobilization is possible for the patient, and successful wound closure is feasible.

Our early results with the dynamic wound closure method have demonstrated cosmetically acceptable, delayed primary closure of difficult fasciotomy wounds in a timely manner. Its advantages over other currently available wound closure methods include versatile and straightforward bedside application; the ability to close large skin defects or defects that exhibit excessive tension; and adequate and customized tensile strength, elasticity, and durability over a full range of motion. The dynamic wound closure method will need to be evaluated in formal comparative studies in which it is applied at the time of fasciotomy. This method also merits further clinical evaluation in other complex surgical wounds, such as in the setting of abdominal wound dehiscence. The report of this series of patients describes the first application of this dynamic wound closure method to patients and our institution is currently undertaking a prospective trial to determine the applicability and parameters for its use. In anticipation of the prospective study, this article describes our anecdotal results with this dynamic wound closure method and explains the physiologic principles behind its design.

Author Contributions
Study conception and design: Reitsma, Bell
Acquisition of data: Sarazin, Bell
Analysis and interpretation of data: Taylor
Drafting of manuscript: Taylor
Critical revision: Reitsma, Sarazin
Supervision: Bell

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