Chapter 9
Fasciotomy Wound Management

Vasilios G. Igoumenou, Zinon T. Kokkalis, and Andreas F. Mavrogenis

Problem Background

- Surgical fasciotomy is the only effective treatment, offering an immediate decrease in the compartment pressure and an increase in the volume of the affected muscle compartment through the release of the skin and muscle fascia.
- Complications of fasciotomy include long hospital stay, wound infection and osteomyelitis, need for further surgery for delayed wound closure or skin grafting, scarring, delayed bone healing, pain and nerve injury, permanent muscle weakness, chronic venous insufficiency, cosmetic problems, and an overall increased cost of care.
- However, closure of fasciotomy wounds is challenging, and a plethora of techniques have been proposed.
- With no consensus existing in the literature regarding the best method for closure of fasciotomy wounds, the technique applied each time is based mostly on surgeon's preference and other variables, such as the condition of the tissues surrounding the wound, availability of materials and devices, patients' environment and preference, and institutional financial resources.

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V. G. Igoumenou · A. F. Mavrogenis (✉)
First Department of Orthopedics, National and Kapodistrian University of Athens, School of Medicine, Athens, Attica, Greece
e-mail: afm@otenet.gr

Z. T. Kokkalis
Department of Orthopedics, University of Patras, Patras, Achaia, Greece

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Introduction

Acute compartment syndrome is a surgical emergency, in the setting of which immediate actions should be taken to avert muscle and nerve cell death [1, 2]. In order to prevent irreversible tissue necrosis, treatment aims to restore muscle perfusion as quickly as possible [1, 3]. Surgical fasciotomy presents the only effective treatment, offering an immediate decrease in the compartment pressure and an increase in the volume of the affected muscle compartment through the release of the skin and muscle fascia [1, 3]. Nonetheless, fasciotomy carries its own risks and complications, including long hospital stay, wound infection and osteomyelitis, need for further surgery for delayed wound closure or skin grafting, scarring, delayed bone healing, pain and nerve injury, permanent muscle weakness, chronic venous insufficiency, cosmetic problems, and an overall increased cost of care (Fig. 9.1) [2–5].

To reduce the risk of complications, the fasciotomy wound should be closed as quickly as possible [6]. However, early primary wound closure is not recommended as it may lead to increased muscle pressure and recurrent compartment syndrome [2, 5, 7, 8]. As a result, closure of fasciotomy wounds is challenging, and a plethora of techniques have been proposed. With no consensus existing in the literature regarding the best method for closure of fasciotomy wounds, the technique applied each time is based mostly on surgeon's preference and other variables, such as the condition of the tissues surrounding the wound, availability of materials and devices, patients' environment and preference, and institutional financial resources [7, 9]. This chapter aims to summarize the available techniques employed in fasciotomy wound closure and to discuss the indications, advantages, disadvantages, and complications of these techniques in a way that readers may find useful and educative.

Fig. 9.1 (**a**) A 42-year-old man with a crush injury of the leg with tibia and fibula fracture. (**b**) Fasciotomy was done, but because of muscle necrosis and sepsis, he ended with a knee disarticulation

Early Primary Wound Closure

Early primary wound closure of fasciotomy wounds, apart from being rarely possible due to edematous tissues, is also not recommended since it may lead to recurrent compartment syndrome [7]. Split-thickness skin grafting has been widely used for fasciotomy wound closure, as it has been thought to reduce patient morbidity from wound complications and delayed rehabilitation compared to immediately primarily or secondarily closed fasciotomy wounds [10, 11]. The use of skin grafts is associated with donor site morbidity, infection, lack of sensation over the fasciotomy site, risk of graft nonadherence, and poor cosmesis that, at times, requires scar revision or resection [6, 7, 9, 12, 13]. Yet, split-thickness skin grafting remains a viable option when other closure techniques fail or in special cases, as in persistently dehiscent wounds, in burnt or friable wound edges, and in very large skin defects [1, 7, 9]. Additionally, split-thickness skin grafting represents frequently a benchmark for evaluating complications, safety, efficacy, and cost-effectiveness of other newly introduced closure techniques [7, 12].

Delayed Primary Wound Closure

After fasciotomy, the wound is usually managed open and dressed sterilely with moist dressings to protect the tissue from drying and retraction [2, 5]. Alternatively, negative pressure wound therapy (NPWT) can be employed [2, 5, 7, 9, 13–20], or numerous techniques can be performed for staged wound closure aiming for gradual approximation of skin edges once the edema begins to resolve (Table 9.1) [7, 21–51].

Table 9.1 Summary of published studies on dynamic dermatotraction and static tension devices for fasciotomy wound closure

Study	Level of evidence	Technique	Description
Dynamic dermatotraction mechanical devices			
Bulstrode et al. [46][a]	IV	*Op Site closure technique*	Adhesive film dressing (Op Site) applied across the fasciotomy wound is reduced gradually by means of a tensioning rod stuck to the center of the dressing
Hirshowitz et al. [39][a]	IV	*U-shaped hooked arms*	Two pins are threaded through the dermis of the wound margins, and two U-shaped hooked arms engage the pins through the overlying skin surface. A threaded screw passes through the centers of the arms, and when the screw is turned by a tension knob at its free end, the distal arm, which is loose, rides over the screw and is pulled over, facilitating reapproximation

(continued)

Table 9.1 (continued)

Study	Level of evidence	Technique	Description
Narayanan et al. [34]	IV	*Sure-closure* (Life Medical Sciences, Princeton, NJ)	Modification of U-shaped arms. The device is tightened in cycles; 30–90 minutes of tightening are interrupted by 10-minute periods of loosening ("load cycling"). The fasciotomy wound can be even closed intraoperatively
Caruso et al. [47]	IV		
Hussman et al. [35]	IV		
McKeneey et al. [40]	IV	*STAR* (suture tension adjustment reel; WoundTEK Inc., Newport, RI)	One anchoring and one winding shell are connected by heavy-duty nylon mattress suture. The winder shell is tightened at the bedside with the use of a wrench, reapproximating the wound edges, and the wounds are closed under local anesthesia over several days
Wiger et al. [44]	IV	*External tissue extension* (ETE, Hojmed, Loddekopinge, Sweden)	Dermal traction is achieved by silicone bands passing through a slot in a plastic unit consisting of a needle and two friction stoppers counted on a silicone string
Bjarnesen et al. [48]	IV		
Janzing et al. [49]	III	*Marburger plates* (described by Hessmann)	Plates placed along the sides of the wound joined by sutures and progressively tightened
Taylor et al. [50]	IV	*Dynamic wound closure device* (DWC; Canica, Almonte, Ontario, Canada)	Cleated or adhesive skin anchors laced together with silicone elastomers, which can be individually tightened, allowing for constant tension over the entire wound
Singh et al. [42]	IV		
Barnea et al. [38]	IV	*Wisebands* wound closure device (Wisebands Company Ltd, Misgav, Israel)	A tension feedback control device measures the tension on the wound edges during tightening and adjusts accordingly to maintain an appropriate level of tension
Medina et al. [41]	III	*Silver bullet wound closure device* (SBWCD; Boehringer Laboratories, Norristown, PA)	A 9.5-cm stainless steel instrument resembling a silver bullet is sutured into the middle of the wound and tightened daily through the rotation of an internal cylinder gradually contracting the wound
Manista et al. [51]	IV	*DermaClose RC* (Wound Care Technologies, Inc., Chanhassen, MN)	Continuous external tissue expander, providing a constant traction force on surrounding wound skin edge. Barbed skin anchors are stapled uniformly around the wound and a tensiomer applies a continuous controlled pulling force on a heavy suture that is "laced" to the skin anchors

Table 9.1 (continued)

Study	Level of evidence	Technique	Description
Topaz et al. [43]	IV	*TopClosure* 3S system (IVT Medical Ltd., Ra'anana, Israel)	Comprises two attachment plates that are interconnected by a long, flexible approximation strap. The strap links the opposing plates, enabling approximation and advancing the plates by incremental pull on the strap. The plates are attached to the skin either by staples/sutures or by hypoallergenic, biocompatible adhesive
Static tension devices			
Mbubaegbu and Stallard [33][a]	V	*Plaster strips*	Serially applied longitudinal plaster strips on either side of the wound bridged by plaster bridging strips, and twice weekly the strips are changed, so as to gradually achieve wound closure
Harrah [32]	IV	*Steri-Strips* (3M Surgical Products, St Paul, MN)	Steri-Strips are used instead of plaster
Rogers [12][a]	III	*Staged linear closure*	Progressive wound closure as the swelling subsides. Areas left open between stages are covered with a vacuum-assisted wound dressing

[a]Original report of the technique

Negative Pressure Wound Therapy

Negative pressure wound therapy (NPWT) or vacuum-assisted wound closure can be applied in various ways in fasciotomy wound management depending on different wound conditions, progress of healing, and surgeon's preference. First, it can be used as an alternative to the wet-dry dressings, which are traditionally used immediately after fasciotomy [5, 7]. Second, NPWT can be used as a definite treatment of fasciotomy wounds until wound healing is accomplished [1, 2, 5–7, 9, 13]. Third, NPWT can be used as an adjunct to other closure techniques [2, 7, 9, 13]. Initially introduced in the late 1990s [14], NPWT has been widely used in the management of challenging wounds. It involves the use of a foam dressing, covered by an adhesive drape that is connected to a vacuum pump in order to create subatmospheric pressure on the wound that is equally distributed, creating a controlled closed wound [9, 14]. Its therapeutic properties regarding fasciotomy wounds result from the positive effects of subatmospheric pressure. Moreover, as excess fluid is drained from the affected compartment, extracellular edema and tissue swelling are reduced, thereby compartment pressure is further decreased [1, 5, 7, 9, 13, 15]. Furthermore, local blood flow is improved, a moist environment is preserved, retraction of wound edges is prevented, bacterial count may also be decreased, and angiogenesis can be stimulated, leading ideally to improved wound healing and decreased risk of infection [1, 5, 7, 9, 13–15]. Researchers have found that with NPWT fasciotomy wounds can be closed earlier and with less need for skin grafting; when used as a bolster for skin grafts, it has been found to promote graft adherence and prevent potential hematoma or seroma formation [13, 16, 17].

The drawbacks of NWPT compared to other closure techniques in terms of morbidity, cost-effectiveness, and length of treatment have been reported in related studies [6, 7, 15, 18]. More specifically, in a recent randomized trial, NWPT was associated with increased need for skin grafting, increased cost, and longer duration of treatment as compared to the shoelace technique [6]. Increased need for skin grafting after NPWT was also found in another large retrospective study compared to patients treated with saline-soaked gauze packing and vessel loop dermatotraction [18], which is in accordance with the findings from other studies in which NPWT was related to incomplete healing and increased need for additional skin grafts, thereby increasing duration and cost of treatment [7, 15]. NPWT has been further associated with overgranulation that may delay epithelialization and with granulation tissue growing into the sponge creating nidi prone to inflammation or infection [6, 19]. In cases with massive muscle swelling, the wound edges cannot be sufficiently contracted by NPWT, and the tissues tend to become increasingly rigid due to granulation, further limiting complete approximation of the skin margins [6]. The use of NPWT in wounds with active bleeding should be avoided as well, since arterial erosion and bleeding have been reported [20]. In the same scenario, when a vascular reconstruction has been performed, NPWT is contraindicated [7].

Gradual Suture Approximation

Cohn et al. [21] were the first to describe a gradual suture approximation technique for fasciotomy wounds named the shoelace technique that represents one of the most widely applied methods in the management of fasciotomy wounds. Staples are placed along the wound edges, and a vessel loop is threaded through these staples in a crisscross fashion, like a shoelace (Fig. 9.2). Afterward, the loop is tied under light tension and tightened every 48 hours at the bedside [21]. When the wound edges are adequately approximated for suturing (typically within 1 cm), a second operation is performed and delayed primary closure can be accomplished [13, 22].

The shoelace technique is a simple, safe, and inexpensive method to bring the skin margins together gradually as swelling resolves [7, 13]. It does not interfere with external fixators or limb and patient mobilization and usually results in a fine linear scar, without the need for skin grafting [7, 23]. Although not being a major

Fig. 9.2 (**a**) A 46-year-old man with a two-bone forearm fracture. (**b**) Clinical examination at presentation showed severe, constant pain, increased pain on passive stretch of the wrist and fingers, paresthesias, and weakness at the distribution of the median and ulnar nerves; radial artery pulses were intact. Fracture osteosynthesis and (**c**) volar fasciotomy was done with gradual fasciotomy wound approximation with a shoelace technique. (**d**) Delayed primary fasciotomy wound closure was done at 2 weeks, (**e**) with excellent cosmesis and function at 6 months postoperatively

Fig. 9.2 (continued)

drawback, staple detachment often occurs secondary to point loading from tightening or limb mobilization; therefore, staples need to be checked and replaced where necessary. Marginal ischemia and/or skin necrosis may rarely occur, again due to point loading at the staple sites [7]. Several modifications of the original technique have been described, aiming to improve the technique and eliminate its weaknesses. Nylon sutures have been used instead of vessel loops, as the latter are not designed for wound closure and lack the essential strength to close large defects [7, 24]. The use of paper clip to secure the vessel loop ends was also described as an alternative to knots, in order to maintain tension [23]. The use of subcutaneous [25] or intracutaneous nylon sutures [22, 26] that are gradually tightened at bedside may achieve direct final closure of the wound without the need for a reoperation. However, replacing these sutures in case they break during approximation is not as easy as replacing sutures or loops threaded through staples [7, 25]. Furthermore, they present an increased risk for skin necrosis. A modification of these techniques is to pass the sutures through catheters, to avoid direct contact of the sutures with the underlying soft tissues [27]. Gradual tightening of a silicon sheet that is fixed without tension and covers completely the wound has been proposed as a safe, painless and cost-effective method that may be associated with a reduced risk of infection and improved cosmetic results [28]. Other surgeons described the application of Ty-Raps (Thomas & Betts, Memphis, Tennessee, USA) that are stapled to the skin and individually tightened each day [29].

Callanan and Macey used fine subcuticular Kirschner wires along both sides of fasciotomy wounds with an elastic band that was stapled in a shoelace pattern to the wound edges and, at the same time, to the underlying Kirschner wires, thus creating an even distribution of tension along the skin edges during approximation, thereby preventing ischemia [30]. A simpler suture technique described by Dahners for fasciotomy wounds is the running "near-near-far-far" stitch; the near stitch is passed 5 mm to 10 mm from the wound edge, and the far stitch is passed 3 cm to 6 cm from the wound edge [31]. According to Dahners, running of the suture balances the tension throughout the wound and allows the suture to be tightened once swelling has receded [31].

In general, suture approximation techniques are widely popular in the management of fasciotomy wounds because of good to excellent outcomes with high wound closure rates, use of inexpensive and easily accessible materials that are available in healthcare facilities with limited resources, and ease of application and the suture tightening that can be safely performed even in an outpatient setting [7, 9, 29]. Wound closure with suture approximation is expected to occur within 5 days to 3 weeks [6, 7, 22, 23]. Complications such as ischemia or increase of compartmental pressures, though rare, may occur; therefore, continuous evaluation of the wound is recommended.

Dynamic Dermatotraction and Static Tension Devices

Although numerous methods and devices have been developed for the management of fasciotomy wounds, none managed to gain wide popularity, while their use has been mainly reported as single specific-center experience [7]. Static and dynamic traction techniques have been described with variable results, effectiveness, and related complications. Regarding the application of static tension methods [12, 32, 33], plaster and Steri-Strips cannot reliably apply forces required to close large fasciotomy wounds with severely protruding muscles [7]. Staged linear closure, on the other hand, requires multiple operative procedures until wound closure is achieved; NPWT should be additionally applied in staged linear fasciotomy wound closure, as originally described by Rogers et al. [12], therefore further increasing the cost of treatment. Dynamic dermatotraction mechanical devices have yet to prove their effectiveness and simplicity, since they are associated with significant costs without decreasing morbidity as compared to other techniques [9]. The sure-closure technique as described by Narayanan [34] was reported to achieve primary wound closure; intraoperative wound closure was obtained in 21 of 24 patients in a maximum of 100 minutes. The technique relies on skin's viscoelastic properties; periods of skin tightening (30–90 minutes) are interchanged ("load cycling") with short periods (10 minutes) of loosening. However, apart from being expensive, when used for long periods of time, it may increase intracompartmental pressures and thereby the potential for skin and muscle necrosis [35].

Higher-level studies evaluating and comparing techniques for static and dynamic delayed fasciotomy wound healing are yet to be reported [36]. These techniques exploit skin's inherent viscoelastic properties. Mechanical creep defined as the elongation of the skin with a constant load over time beyond intrinsic extensibility is the main property of the skin on which all dermatotraction techniques rely [7, 37]. However, regardless of the device or method applied, the surgeons should always refer to the basic principles of tissue (skin) expansion, with the most important being that application of any tension must be deferred until the edema of the injured limb subsides. In case skin expansion is initiated too early and/or too rapidly, the risk for skin edges necrosis, delayed healing, recurrent compartment syndrome, infection, failure of wound closure, and hypertrophic scarring is increased [11, 22, 34, 35, 38–44]. Signs of excessive tension are patient discomfort during or after manipulations and the pale color of skin ischemia [7].

Secondary Wound Closure

It is generally accepted for fasciotomy wounds to be initially left open and then managed by delayed primary closure. However, in the past, fasciotomy wounds were managed open, and closure was attempted by secondary intention [7, 9]. This technique has been abandoned nonetheless, due to unacceptable high infection rates, increased risk of muscle necrosis and sepsis, prolonged hospitalization, delay in rehabilitation, and excessive scarring [7, 9, 11, 45]. It may be reserved though only for fasciotomy wounds, where delayed primary closure has failed due to underlying infection or wound dehiscence [7].

Conclusion

Currently, there is no consensus regarding the optimal technique for fasciotomy wound closure. High-level studies are missing, and the use of complex devices for wound closure after fasciotomy is not substantially advantageous over standard techniques such as suture approximation techniques [7, 9, 13]. Primary wound closure with direct wound edge approximation should be avoided due to high risk of tissue necrosis and persistent or recurrent compartment syndrome. After the initial management, fasciotomy wounds should be regularly inspected as surgical debridement may be necessary within 48–72 hours [2] until the wound presents viable, non-necrotic tissues and muscles [5, 13]. For patients with poor compliance, atrophic or friable skin, infection, or questionable viability of the skin and surrounding tissues, skin grafting is probably the most preferable option. The advantage of NPWT and dermatotraction mechanical devices over shoelace and simple suture techniques has not been documented [6, 7, 9]. In terms of complications though, NPWT has been associated with the lowest rates (2.49%), followed by suture approximation (14.83%) and dynamic dermatotraction (18.4%). It is therefore implied that for patients at high risk of complications, NPWT may be the treatment of choice, whereas when primary closure is the main goal, suture approximation or dynamic dermatotraction devices should be preferred [9]. Treating surgeons should be familiar with every technique, as well as with their advantages and limitations, and patients' selection should be performed for the optimum functional and aesthetic outcomes.

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