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Original Research Article

Structural anatomy of deep fascia, it's implication in the pathogenesis of compartment syndrome of upper limbs and objective assessment of the effect of fasciotomy

Neeraj K. Agrawal[1]*, Preeti Agrawal[2], Rahul Dubepuria[3]

[1]Department of Plastic Surgery, Banaras Hindu University, Varanasi, Uttar Pradesh, India
[2]Department of Oculoplastic Surgery, Eye Care Clinic, Varanasi, Uttar Pradesh, India
[3]Department of General Surgery, Sri Aurobindo Institute of Medical Sciences, Indore, Madhya Pradesh, India

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***Correspondence:**
Dr. Neeraj K. Agrawal,
E-mail: agrawalnk@yahoo.com

ABSTRACT

Background: Deep fascia is dense and well developed in limbs. In the upper limb the deep fascia is tightly adherent to the underlying muscles especially in the forearm, thereby, restricting the space available to muscular swelling causing painful compartment syndrome. Division of this inelastic fascia or fasciotomy is an emergency procedure to decrease the morbidity and mortality.
Methods: 30 patients with acute compartment syndrome of the upper extremity of various aetiologies were studied. Adults with painful, swollen and tense upper extremities with progressive neurological dysfunction were studied. Compartment pressures before and after fasciotomy were measured by a standard Whiteside's device. Various fasciotomies were carried out and associated skeletal and vascular injuries were also noted.
Results: The majority of patients were males with average age being 29.33 years. 56.67% patients with upper limb compartment syndrome sustained road traffic injury, 20% were constrictive tight cast, 20% of patients sustained burn and 1 patient was shot by bullet. Of the 30 patients fractures of both ulna and radius (40%) were the most common. Fractures of the humerus, radius, ulna and small bone of metacarpals together account for 36.67% of the affected patients. 3 patients were found to have injury to major vessels. Compartment pressure was measured by Whiteside's device and fasciotomy resulted in a drastic drop of the pressure from pre-fasciotomy pressure of 44.8±7.9 mmHg to post-fasciotomy pressure of 12.33±3.61 mmHg.
Conclusions: The diagnosis of compartment syndrome should be confirmed swiftly and prompt fasciotomy is the treatment of choice. This offers the best chance at decreasing compartment pressure and preventing further damage.

Keywords: Compartment pressure, Compartment syndrome, Deep fascia, Fasciotomy, Upper limb, Vascular injury

INTRODUCTION

Few conditions have the potential to threaten the viability and usefulness of the extremities, compartment syndrome being one of them. It is characterised by raised pressure in closed fascial compartments which result in circulatory and neuromuscular ischaemic insult and compromise leading to pain, pallor, pulselessness and eventually paresthesias. Fasciotomy is a procedure where the compressing fascia is cut to relieve compartment pressure and allow the muscle to swell, decrease pressure, and restore blood flow and nerve function.[1,2] The fact that fasciotomy relieves the patients of excruciating pain due to such tight fascial compartments is a good enough reason to study the structural anatomy of deep fascia. It is also imperative to decipher its role in the pathogenesis of compartment syndrome.

Deep fascia is wavy connective tissue composed mainly of collagenous fibres which are compacted and regularly arranged such that the deep fascia may be indistinguishable from aponeurotic tissue.[3] The fibers are usually oriented in one direction so that the structure does not become loose or lax. In limbs, where the deep fascia is well developed, the collagen fibres are longitudinal or transverse, condensing into a tough, inelastic sheath around the musculature. In Latin, fascia means "bundle, bandage, strap, unification, and binding together".[4] Clinically, they may be significant in restricting the space available to muscles, causing pain syndromes when the volume of a muscle expands, for example as a result of oedema. The unyielding character of the deep fascia contains and separates groups of muscles into relatively well-defined spaces called compartments. The deep fascia integrates these compartments and found in conjunction with the associated bones as well as intermuscular septa and, therefore, also called osteofascial compartments. Each segment of the limbs like arm, forearm, thigh, leg or foot have their own characteristic compartments separating functional groups of muscles with distinctive embryological origins, blood and nerve supplies.[5]

Volkmann et al described the consequences of increased compartmental pressures as a result of acute compartment syndrome. Volkmann described, for the first time, ischemic muscle contracture of the flexors of forearm as: ‘‘the severe contractions, after applying too tight of a bandage on the fore arm for a fracture, are at least partially due to infectious muscle contraction and not all cause pressure induced primary nerve lesions".[6,7] In 1906, Hildebrand suggested that untreated compartment syndrome can lead to elevated tissue pressure and may cause ischemic contractures. Bardenheuer believed that it entirely had vascular pathology and the toxins which accumulated as a result of obstruction of venous out flow resulted in muscle degeneration.[8] However, Thomas postulated not only circulatory disturbance but also nerve injury as the cause.[9]

Interstitial tissue pressures or compartment pressures can be measured indirectly by measuring the amount of pressure necessary to overcome the compartmental pressure during the injection of a small amount of saline into the affected compartment, continuous monitoring technique, Wick catheter using a special catheter with pressure-sensitive filaments protruding from its tip or slit catheter.[10-13] New technologies such as laser Doppler flowmetry and 99mTc-methoxy-isobutyl-isonitrile scintigraphy are less invasive but impractical in the emergency setting and are not yet cost-effective.[14-16]

Tight fascial compartments necessitate fasciotomy to prevent nerve injury and contracture development. The first reported fasciotomy for acute compartment syndrome was by Ueber, in 1888.[17]

This work was undertaken to study the effect of deep fascia on the pathogenesis of compartment syndrome by measuring the compartment pressure before and after fasciotomy.

METHODS

This study was conducted on 30 patients with acute compartment syndrome of various aetiologies involving the upper extremity. It was carried out in the Department of Plastic Surgery, Banaras Hindu University, Varanasi, India between January 2019 to December 2019. A thorough history and physical examination were carried out (Table 1). Adults with painful, swollen and tense extremities were included in the work. Children <12 years and psychiatric patients were excluded owing to assumed non-cooperation. They also have an inconsistent perception and description of pain and may not communicate pain accurately.

Table 1: Clinical characteristics of the patients.

Clinical characteristics	
History	Examination
High/ low-energy injury mechanism	Pain on passive stretch
Multiple trauma	Pain out of proportion to the nature of injury
Associated injuries	Tense and swollen compartment
Medical comorbidities	Progressive neurologic dysfunction
Anticoagulants	Pallor

Pain out of proportion to the injury was found to be an early finding in patients with compartment syndrome. This symptom with a tense, oedematous limb, pain on passive stretch and progressive neurological dysfunction were the prime parameters to decide the enrolment of subjects. Progressive neurological dysfunction was defined as an orderly sequence of loss of light touch, hypesthesia, progressive motor weakness and anesthesia. Roentgenographic survey was performed to diagnose fractures of upper extremity. Nerve conduction studies was done to confirm the neurological loss.

The compartment pressure was measured by Whiteside's device. The instrument was set up as shown in Figure 1. A sterile 18-gauge needle was used to measure the compartment pressure and was advanced to just pierce the deep fascia into the muscle. At 3 o'clock of stopcock and the syringe filled with 10 ml air, the needle was inserted into a fresh bottle of saline with a drop of methylene blue and about 1 ml of this stained saline was sucked through the needle by the 20 ml syringe to fill 1/3 of the intravenous tube (Figure 1). The rest of the system consisted of only air. At 6 o' clock position of the triway the plunger of the 20 ml syringe was gradually moved to push air equally into both the intravenous tubes. The moment the dyed saline just started to move in the manometer, the reading was noted by an assistant. The manometer reading denoted the compartment pressure which decided whether it was prudent to do a fasciotomy.

Different regions of the upper extremities were managed by specific fasciotomies.

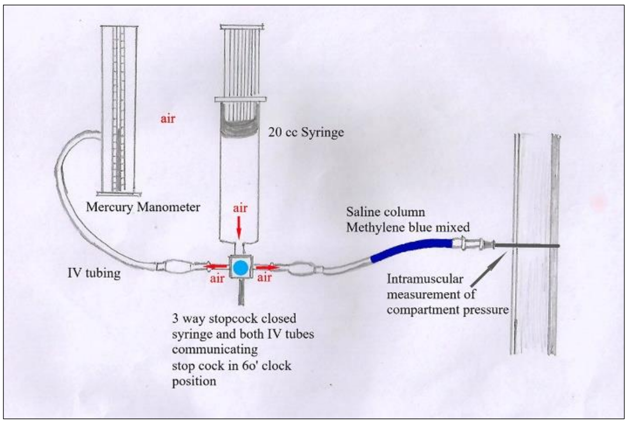

Figure 1: Components of Whiteside's device.

The two upper arm muscle compartments were released by a lateral skin incision from deltoid insertion to lateral epicondyle with mobilisation of skin flaps (Figure 2). The intermuscular septum between the anterior and posterior compartment was identified and the fascia over each compartment was incised longitudinally. Radial nerve was specially taken care of in the posterior compartment.

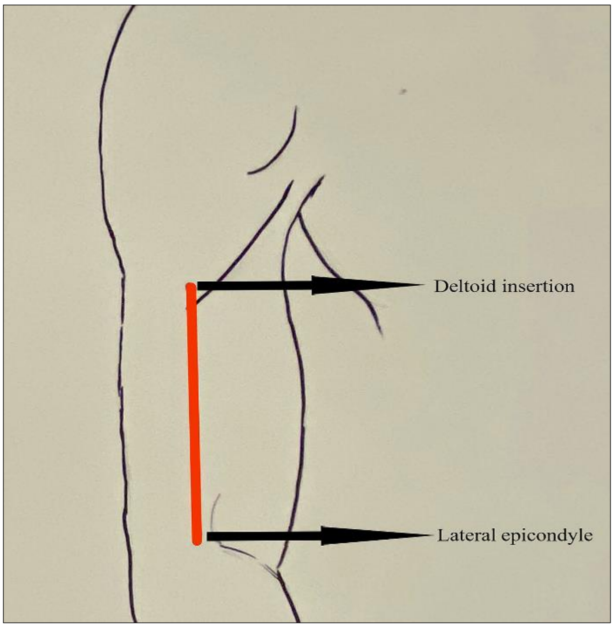

Figure 2: Upper arm fasciotomy through a single lateral skin incision from deltoid insertion to lateral epicondyle.

Forearm was released by a "lazy S" volar skin incision which extended from just proximal to the antecubital fossa to the mid palm just ulnar to thenar crease. The deep fascia encasing the flexor muscle bellies was opened. Decompression of the median nerve was done by releasing the carpal tunnel well distal to the wrist (Figure 3).

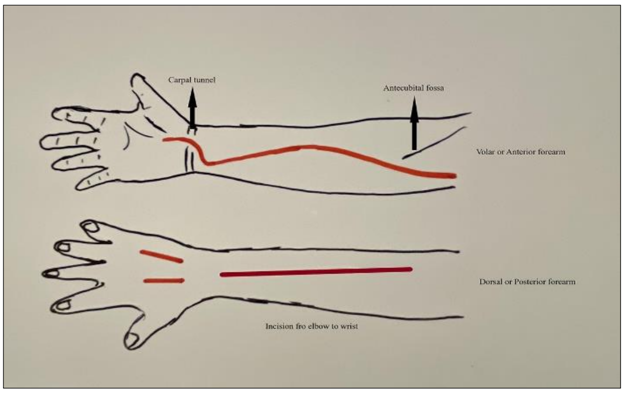

Figure 3: Volar and dorsal incisions for performing fasciotomy of the forearm and the hand

The posterior compartment was opened with a longitudinal incision from the elbow to the wrist between the mobile extensor wad and the extensor digitorum muscle (Figure 3).

The hand was released by carpal tunnel release and two dorsal incisions over the second and fourth metacarpal spaces between the extensor tendons (Figure 4).

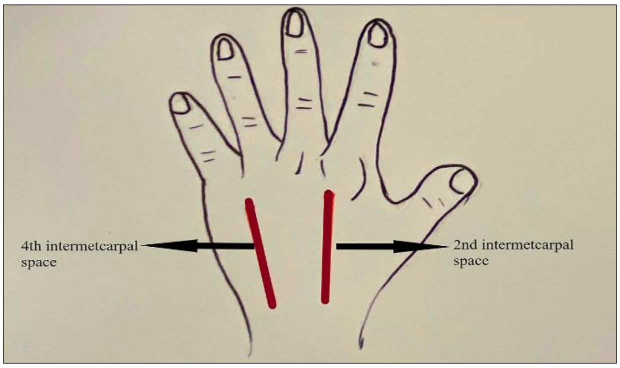

Figure 4: The interosseous compartments of the hand were decompressed by incisions placed on the dorsum over the second and fourth intermetacarpal spaces.

Following appropriate and adequate fasciotomies, identified by immediate bulge of muscles in open fasciotomy, the compartment pressure was measured 4-6 hours after the procedure.

All the data were recorded and tabulated. Pre and post procedure photographs were obtained. Quantitative variables were statistically analyzed by mean, median, standard deviation, maximum and minimum value. The data pertaining to measurement of compartment pressure were subjected to z-test and p-values calculated.

RESULTS

The demographic variables of all the 30 patients were studied and we found 83.33% (25 of 30) were males. The mean age was 29.33±11.35 years ranging from 12 to 53 years and median being 31.5 years (Table 2). The causes of compartment syndrome of upper limb were diverse (Figure 5). 56.67% patients sustained road traffic injury, 20% were bony injuries which were managed by tight cast and resulted in compartment syndrome and same proportion of patients sustained thermal (2 of the 6 patients) or electrical burn (4 of 6 patients) and 1 patient was shot from an intermediate distance by a firearm (Figure 6 and Table 2). The effect of various injury patterns resulted in various bony injuries, in 76.67% of patients, apart from burn. Fractures of the humerus (10%), radius (16.67%), ulna (6.67%), both ulna and radius (40%) and small bone of metacarpals (3.33%) (Figure 7 and 8 and Table 2). 3 patients were found to have injury to major vessels (Figure 9). Measurement of compartment pressure by Whiteside's device yielded pre-fasciotomy pressure of 44.8±7.9 mmHg (range 36-60 mmHg). The significant compartment syndrome was managed by open fasciotomy and there was drastic drop in the pressure after fasciotomy which was calculated to be 12.33±3.61 mmHg (range 6-20 mmHg) but the drop in the pressure was statistically not significant as p value was >0.05.

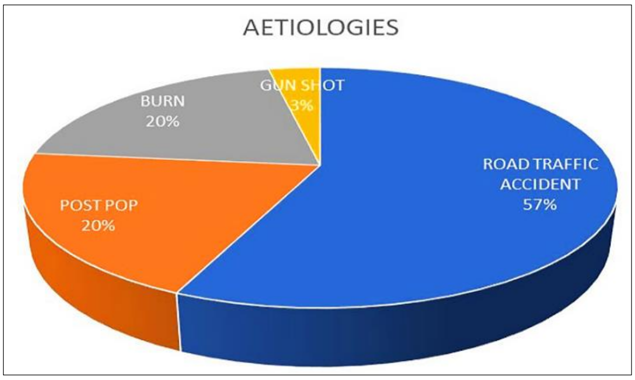

Figure 5: Different causes of compartment syndrome in this pie chart.

Figure 6: Compartment syndrome arm and forearm due firearm injury with only tingling at the tip of index finger, doppler showed pseudoaneurysm of the brachial artery, pseudoaneurysm excised and brachial artery repaired. X-ray shows bullet lying near the humerus.

Figure 7: A 8-hour old case of fracture both bone forearm.

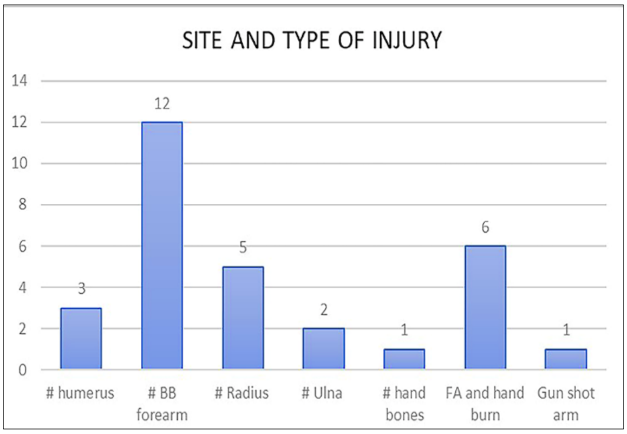

Figure 8: Bones of upper limb that were fractured and their distribution causing compartment syndrome.

Figure 9: 6 hours old case of dislocated fracture of humerus with absent pulses, fasciotomy done (inset), brachial artery found ruptured which was repaired and the patient improved.

Table 2: Synopsis of the 30 patients included in the study.

Age (years)	Sex	Etiology	Site of injury	Vascular injury	Pre-operative CP	Post-operative CP
36	M	Post POP	# BB forearm with severe dislocation	No	50	10
19	M	Thermal burn	Forearm and hand	No	40	16
31	M	RTA	# BB forearm	No	40	20
18	M	Electrical burn	Distal forearm and hand	No	40	8
34	M	RTA	# BB forearm	No	50	14
22	M	Post POP	# Radius shaft	No	40	16
45	M	RTA	# BB forearm	No	38	18
12	F	RTA	# Ulna with severe dislocation	Yes	36	10
36	M	Electrical burn	Forearm and hand	No	60	10
16	F	Electrical burn	Hand	No	46	16
30	M	Post POP	# Ulna	No	60	12
22	F	RTA	# Humerus	No	36	12
34	M	RTA	# BB forearm	No	42	8
32	M	RTA	# Radius	No	40	6
26	M	RTA	# BB forearm	No	40	16
42	M	Gunshot	Arm	Yes	36	12
44	M	RTA	# Radius	No	60	10
50	M	RTA	# BB forearm	No	42	10
42	M	RTA	# Humerus	No	60	16
22	F	RTA	# BB forearm	No	42	12
42	M	Post POP	# BB forearm	No	44	8
28	M	RTA	# Radius	No	38	8
53	M	Thermal burn	Forearm and hand	No	56	14
13	F	RTA	# BB forearm	No	40	8
16	M	Post POP	# Radius with dislocation	No	56	8
17	M	RTA	# Humerus	Yes	36	12
13	M	Post POP	# BB forearm	No	40	14
33	M	RTA	# Hand bones	No	44	16
32	M	RTA	# BB forearm	No	42	12
35	M	Electrical burn	Forearm	No	50	18

POP=plaster of Paris, RTA=road traffic accident, #=fracture, BB=both bone, CP=compartment pressure

DISCUSSION

Compartment syndrome is a limb- and life-threatening condition which can become ominously dangerous owing to delayed diagnosis. Unrecognized acute compartment syndrome can leave patients with nonviable limbs requiring amputation. Glass et al summarized 21 amputations in 63 limbs of missed compartment syndrome.[18] Schwartz et al reported a mortality rate of 47% in patients with acute compartment syndrome.[19] Volkmann's ischemic contracture is another complication resulting in permanent disability.[8]

Direct injury to extremities with or without fracture has been cited as the most common cause of compartment syndrome in various studies and account for about 69-75% cases.[1,20] 76.67% of 30 subjects in our study sustained upper limb trauma, of which 56.67% of patients with compartment syndrome suffered high velocity direct blow to the extremity and 20% developed raised tissue pressures due to constrictive plaster casts applied for closed manipulation of upper limb fractures. The crush component in the upper limb may cause damage to muscle with cellular injury and break down that increases pressure within a limited fascial space. At the same time fractured bones and consequent hematoma formation also increase the intracompartmental volume and, therefore, high intracompartmental pressure.

Mubarak and Carroll reported on 55 cases of Volkmann's contracture, 22 of which (40%) involved the upper extremity.[21] The most common cause in these patients was supracondylar humerus fracture. In a series reported by Eaton and Green 83% of skeletal trauma-related forearm compartment syndrome was caused by supracondylar humerus fractures.[22] In our study, only 10% of patients who developed compartment syndrome sustained humerus fractures. However, it accounted for 13% of skeletal trauma (3 of 23 patients). Dislocated fractures of both forearm bones, the radius and the ulna, account for 52.17% (3 of 23 patients). This site predilection was also reported by Bajpai et al who studied 138 cases of Volkmann's contracture and found the most common cause of forearm compartment syndrome to be radius and ulna fracture, with supracondylar fracture next.[23] Acute volar compartment syndrome as a complication of isolated fractures of the distal radius have also been reported.[24] We observed in our work that fracture of radius alone resulted in 21.74% all skeletal trauma with established compartment syndrome. A significant number of compartment syndromes have been described in open fractures.

Another cause of compartment syndrome in our work was burns (20%) commonly due to electrical or circumferential third-degree burns. In high-voltage electrical burns, the underlying muscle tissue through which the current passes is frequently injured and hence becomes swollen and edematous.[25] Accumulation of tissue fluid or by the extrinsic compression by the burned tissue acting as a tourniquet results in high compartment pressures. The rigid deep fascia and the compartments that surround the injured muscle inversely affect the perfusion of the tissues threatening the viability of the limb if left untreated. Circumferential third-degree extremity burns need emergent escharotomy of the rigid burn eschar as it does not expand because of extrinsic compression on the extremity.

The most common muscle compartment in the upper extremity affected by compartment syndrome is the anterior or flexor compartment of the forearm. The upper arm is the least commonly affected, because it has a greater capacity to swell before the compartment pressures increase.[26]

The pressure of a normal myofascial compartment is usually quoted to be less than 10 mm Hg. In the work performed by the authors' post-fasciotomy pressure was calculated to be 12.33±3.61 mm Hg which can be considered baseline pressure. Some authors have stated that an absolute intracompartmental pressure (ICP) of 30 mm Hg is an indication for fasciotomy due to studies showing that ICP sustained at this level for 6-8 hours results in irreversible damage.[12] However, others have argued that ICP should be related to the systemic diastolic pressure to determine the critical pressure (also called Δp).[27] There is some controversy regarding the threshold of Δp at which surgical intervention is warranted but is usually quoted to be between 30 mm Hg and 45 mm Hg. Mubarak et at inferred that fasciotomy should be performed in normotensive patients with positive clinical findings, who have compartment pressures of greater than 30 mm Hg, and whose duration of increased pressure is unknown or thought to be longer than 8 hours.[28] We performed fasciotomy when compartment pressures were 44.8±7.9 mm Hg.

However, few workers suggested primary amputation in subjects with clinical evidence of acute compartment syndrome with a probable duration of more than 8 hours, with absence of muscle function in a neurologically intact limb.[29]

Additional injuries involve vascular trauma that usually threatens the viability of the limb. Statistically, approximately 10% of combat injuries are vascular injuries, 75% of which are extremity vascular injuries.[30]

CONCLUSION

The well developed and inelastic deep fascia of the upper limbs cause painful compartment syndrome when volume of the encased muscles increases. High index of suspicion and early diagnosis of compartment syndrome helps a surgeon to avoid unnecessary complications. Once the diagnosis of compartment syndrome has been confirmed, prompt fasciotomy is the treatment of choice and offers the best chance at decreasing compartment pressure and preventing further damage.

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