Chapter

Hand Compartment Syndrome

Ioannis M. Stavrakakis, George E. Magarakis and Theodoros H. Tosounidis

Abstract

Compartment syndrome is defined by high pressures in a closed myofascial compartment, which affects initially the muscles and later the nerves and vessels. The hand is rarely affected, but if treated suboptimally, it results to a permanent loss of function. Eleven compartments are included in the hand and wrist. Diagnosis of compartment syndrome of the hand remains challenging. Pain out of proportion of injury and excessive swelling should raise suspicion towards a compartment syndrome. Intracompartmental pressure measurement contributes to the diagnosis, but it is not always reliable. Once the diagnosis of acute compartment syndrome has been made, decompression of all compartments is mandatory, in order to achieve a good outcome. Failing to manage this emergent condition properly leads to a significant hand disability. Our chapter includes the following sections: 1. Introduction. A brief description of the hand compartment syndrome is presented. 2. Anatomy. Special considerations regarding hand compartments are presented, 3. Etiology. 4. Diagnosis. Signs and symptoms are reported, as well as guidelines of the technique of intracompartmental pressure measurement. 5. Treatment. Faciotomies' indications and operative technique are described in details. 6. Conclusion. Appropriate figures of the clinical image and surgical decompression are presented as well.

Keywords: hand, compartment syndrome, intracompartmental pressure, surgical decompression, fasciotomy

1. Introduction

Compartment syndrome is defined as an elevated pressure of an anatomical compartment up to a level where the tissue blood perfusion is impeded. Acute compartment syndrome (ACS) of the hand is rare, as compared to other areas of the human body, but the consequences are detrimental if treated suboptimally. Severe functional disability of the hand, due to muscles' contractures, is the inevitable result of a neglected compartment syndrome. Diagnosis of this urgent situation is challenging and it is based mainly on the clinical examination [1–3].

In case there is any doubt towards the diagnosis of ACS or for insensate patients, intracompartmental pressure measurement is used to aid the evaluation [4]. Good knowledge of the special anatomy of the hand is necessary, in order to manage compartment syndrome appropriately. Disproportionate pain, severe swelling and a relevant mechanism should raise a strong suspicion of a compartment syndrome [5]. Once the diagnosis of an ACS is made, treatment should be implemented promptly. Intervention varies from simple actions, such as splitting a tight cast, to a surgical decompression [2]. Correct timing of fasciotomies is of paramount importance, in order to achieve a good functional outcome [6].

This chapter aims to present the current concepts regarding hand compartment syndrome. Special features of the hand compartments' anatomy are reported. Pathophysiology is described briefly, as it is analyzed in extension in other parts of this book. Etiology, diagnosis, treatment and complications are mentioned as well, emphasizing towards the proper technique of fasciotomies.

2. Anatomy - pathophysiology

Hand contains basically ten myofascial compartments: the adductor pollicis compartment, four dorsal interossei and three palmar interossei compartments, the thenar and the hypothenar compartment. The thenar compartment includes the Abductor Pollicis Brevis (AbPB), the Flexor Pollicis Brevis (FPB) and the Opponens Pollicis (OP) muscles. They are innervated by the recurrent motor branch of the median nerve, apart from the deep head of the FPB, which is innervated by the deep branch of the ulnar nerve [2]. The hypothenar compartment includes the Opponens Digiti Minimi (ODM), the Abductor Digiti Minimi (AbDM) and Flexor Digiti Minimi (FDM) muscles. They are all innervated by branches of the ulnar nerve (**Figure 1**). Although located basically in the wrist, the carpal tunnel is frequently mentioned as a compartment of the hand. Cleland and Grayson ligaments also compartmentalize digital space. All compartments of the hand along with their muscles and nerves are presented on the **Table 1** [2, 4, 7]. It is highlighted here that the compartments of the hand contain predominantly motor nerves. Intracompartmental sensory nerves of the hand are only the digital nerves and the median nerve inside the carpal tunnel. This characteristic anatomy is reflected to the clinical image of the compartment syndrome of the hand [4, 5, 8].

Several variations of the hand compartments have been described. Difelice et al. [7] found that in 52% of the hands, the thenar space is separated in two discrete compartments. In 76% of the hands the hypothenar demonstrated at least two compartments. The second, third and fourth interossei group demonstrated different dorsal and volar compartment in the 48%, 67% and 38% of the hands respectively. The fasciotomies used for the treatment of hand ACS are designed based on this anatomic

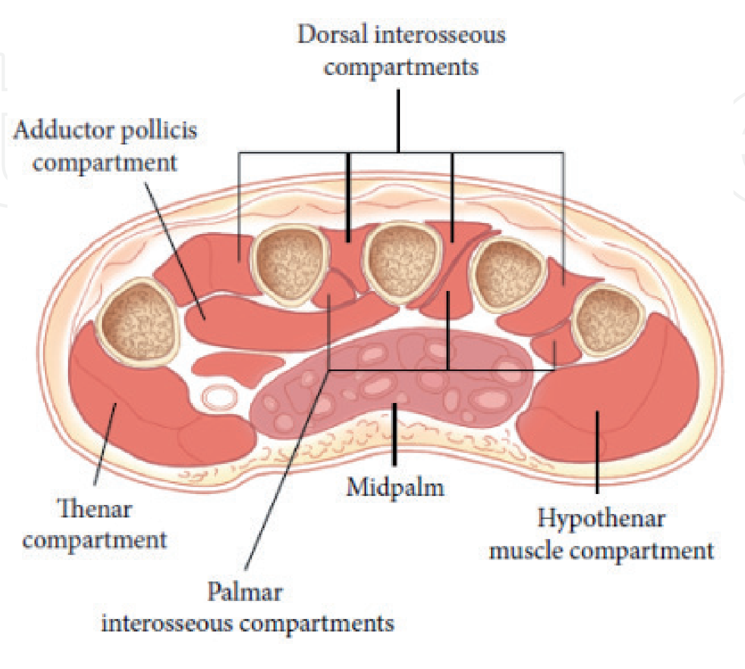

Figure 1.
Hand compartments cross sectional anatomy. (from: Reichman EF. Compartment syndrome of the hand: A little thought about diagnosis. Case rep Emerg med. 2016;2016 [5]).

Compartment	Muscles	Nerves	Incision
Adductor Pollicis	Adductor Pollicis	Sensory: None Motor: Branches of the ulnar nerve	Dorsal over the second metacarpal (radial aspect)
Interossei compartments	4 dorsal interossei, 3 palmar interossei	Sensory: None Motor: Branches of the ulnar nerve	Two Dorsal incsions over the second and fourth metacarpal
Thenar	AbPB, OP, FPB	Sensory: None Motor: Recurrent motor branch of the median nerve, apart from the deep head of the FBP (ulnar nerve)	Radial aspect of the first metacarpal
Hypothenar	AbDM, FDM, ODM	Sensory: None Motor: Ulnar nerve	Ulnar aspect of the fifth metacarpal
Carpal tunnel	None (FPL, 4 FDS, 4 FDP tendons/not muscles)	Sensory: Median nerve Motor: Recurrent motor branch of the median nerve	Midpalmar incision
Digital	None (digital tendons/not muscles)	Sensory: digital nerves Motor: None	Lateral midaxial incision

AbPB: abductor pollicis brevis, OP: opponens pollicis, FPB: flexor pollicis brevis, AbDM: abductor digiti minimi, FDM: flexor digiti minimi, ODM: opponens digiti minimi, FPL: flexor pollicis longus, FDS: flexor digitorum superficialis, FDP: flexor digitorum profoundis.

Table 1.
Compartments of the hand.

model. Whether further subcompartmentalization of the thenar and hypothenar area has any clinical significance is controversial. Gyuton et al. [9] found through a cadaveric study that fascia between dorsal and volar interrossei muscles subsides at pressures as low as 15 mmHg, putting its clinical relevance in question.

The pathophysiology of acute compartment syndrome is based on Matsen's arteriovenous gradient theory. According to this model, interstitial edema increases the local venous pressure (Pv). Local blood flow (LBF) equals to arterio-venous pressure difference (Pa - Pv), divided by vascular resistance (R). Thus, the increase of the local venous pressure decreases local blood flow. Tissue ischemia increases small vessels permeability as well as extravascular osmolality, leading to a further fluid extravasation and subsequent more interstitial edema. Viscious cycle is continued through the former mechanism. Local and systemic inflammatory response is exacerbated by the release of cytokines, as a result of impaired tissue blood supply [4, 10].

Muscle damage due to compartment syndrome occurs prior to nerve impairment and it is reversible for the first 4 hours. The time frame after which muscle necrosis is occurred is still controversial, with a reported range among studies between 8 to 12 hours [2, 4, 11]. Experimental studies of canine model showed permanent tissue necrosis and nerve conduction arrest with interstitial pressures of more than 40 mmHg for at least 8 hours [12].

3. Etiology

Intracompartmental pressure increases by either extrinsic or intrinsic causes or combination of both. Tight dressings or casts represent extrinsic factors, via external pressure application to the compartments of the hand [13].

Figure 2.
Hand crush syndrome. Compartment syndrome due to extensive soft tissue injury and concomitant third and fourth metacarpal fractures, after prolonged compression of the hand by a heavy object.

Figure 3.
Index finger compartment syndrome (delayed presentation), due to high pressure injection injury, complicated with septic tenosynovitis.

Intrinsic causes of hand compartment syndrome are:

1. Trauma: fractures, soft tissue injury, crush syndrome (**Figure 2**),

2. Burns,

DOI: http://dx.doi.org/10.5772/intechopen.95497

Figure 4.
Hand compartment syndrome due to extravasation contrast material. Hand is sitting in intrinsic minus position. Excessive swelling and skin blisters are noticed (from: Stavrakakis IM et al. hand compartment syndrome as a result of intravenous contrast extravasation. Oxf med case rep. 2018;2018(12):omy098 [8]).

3. High pressure injection injuries (**Figure 3**),

4. Iatrogenic: arterial injury, reperfusion surgery, intravenous material extravasation (**Figure 4**),

5. Infection: abscess, septic tenosynovitis, necrotizing fasciitis,

6. Bites (snake, insect),

7. Anticoagulation medications,

8. muscle overuse (exercise, tetany, seizures) [4, 8, 13, 14].

4. Diagnosis

Patient's history, clinical image and physical examination are the keystones for the diagnosis of acute compartment syndrome [2]. Localized swelling and disproportionate pain, unresponsive to analgesics, along with a relative mechanism of injury should raise the suspicion of ACS [2, 4, 13]. As mentioned in the anatomy section, sensory nerves of the hand are located outside the compartments, with the exception of the median and digital nerves. Hence, tingling and paresthesia are not always present, unless the carpal tunnel or digits are involved [4, 5].

Serial clinical examination is of paramount importance, in order to detect ACS early. On inspection, severe swelling is noticed. Blisters might also be visible. The hand is sitting in intrinsic minus position, i.e. the metacarpophalangeal joints (MCPJs) are in extension and the interphalangeal joints (IPJs) are in slight flexion (**Figure 4**) [1, 4, 8]. Digital palpation reveals great tension of the hand. Pain on passive stretching of the intracompartmental muscles is an early sign of impaired blood perfusion. Specifically for the hand, each compartment should be stretched individually. The interossei compartments are stretched by passively abducting and adducting the digits and at the same time keeping the MCPJs in flexion and the IPJs in extension (bring the hand from the intrinsic minus position to the intrinsic plus position - "intrinsic stretch test"). The lumbricals are stretched by passively extending the MCPJ and flexing the proximal IPJ. The adductor pollicis is checked by passively abducting the thumb. Passive adduction of the thumb is used to test the thenar compartment and finally the hypothenar compartment is evaluated by passive adduction and extension of the small finger [2, 13]. In case the five P's of tissue ischemia are already present (pain, pallor, pulselessness, paresthesia and paralysis), then the diagnosis is considered delayed and irreversible muscle damage is very likely. Clinical examination has high specificity as well as high negative predictive value, meaning that it can exclude ACS better than confirming it [15].

In case there is any doubt regarding the diagnosis of ACS after clinical examination, or for unconscious patients, more subjective tools for evaluation should be used. Intracompartmental pressure measurement (ICP) is considered to be the main adjunct to the diagnosis. It is generally accepted that a pressure difference (ΔP) between the diastolic blood pressure (Pd) and the compartmental pressure (Pc) less than 30 mmHg necessitates surgical decompression ($\Delta P = Pd - Pc < 30$ mmHg). This difference is more reliable than an absolute intracompartmental pressure of more than 30 mmHg [15, 16]. Several modalities of measuring the pressure of the compartments have been described, such as the infusion Whiteside apparatus, the slit catheter technique and the handheld intracompartmental pressure monitoring [13]. Straight catheters have the least accuracy as compared to the slit catheter and side port needle. It is also reported that the Whiteside apparatus overestimates the intracompartmental pressure, which can potentially lead to an unnecessary fasciotomy [2, 15]. Current trend is towards a continuous pressure measurement, which is probably more reliable than a single one, as the latter approach is associated with a high false positive rate [17, 18]. As there are cases of silent compartment syndrome described in the literature, i.e. severe swelling with no excruciating pain, whenever there is a slight suspicion of ACS, ICP measurement should be performed [18].

Regardless of the apparatus used, it is crucial that a correct technique of pressure measurement is performed. General guidelines include perpendicular insertion of the needle on the skin [2], within 5 cm of the fracture site, but not in direct contact with the fracture [15, 16]. Particularly for the hand, each compartment's pressure should be measured individually. The hand should rest at the level of the heart. For the thenar and hypothenar compartment the needle is inserted at the border of glabrous and nonglabrous skin. The adductor pollicis muscle is entered ulnarly to the first metacarpal. The interossei compartments are entered between the index-long, long-ring and ring-small finger metacarpal, 1 cm proximal to the metacarpal heads, superficial at first for the dorsal interrosei muscle and then 0,5 to 1 cm deeper for the volar interrosei. Needle insertion over the midpalmar lesion is also used for carpal tunnel pressure measurement (**Figure 5**) [2, 4].

Figure 5.
Portals of intracompartmental pressure measurement of the hand.

Given the fact that clinical examination and intracompartmental pressure measurements have their own limitations, recent research is directed towards hemodynamic and metabolic parameters in an effort to achieve a more accurate diagnosis of ACS. These parameters include: a. Monitoring local oxygenation (via intramuscular partial oxygen pressure, oxygen saturation measurement or near infrared spectroscopy), b. monitoring local perfusion (via pulsed phased - locked loop ultrasound, photoplethysmography, laser Doppler flowmetry and scintigraphy), c. local metabolic analysis (intramuscular glucose monitoring, intramuscular pH monitoring) and d. serum biomarkers (white blood cell count, erythrocyte sedimentation rate, C - reative protein and creatinine kinase). However there is still no evidence of superiority over intracompartmental pressure measurement and there is still long way to go until they can be used safely in clinical practise [16].

Chronic exertional compartment syndrome is defined as a muscle dysfunction because of ICP rising due to excessive activity. Only few cases of chronic compartment syndrome located in the hand have been described in the literature and the most commonly affected compartments are the adductor pollicis, the first dorsal interosseous, the thenar and hypothenar compartments [19].

5. Treatment

Muscles can tolerate a condition of reduced vascular supply for a time period of no more than 6 to 8 hours. Regarding the limbs there is evidence supporting that the time threshold after which necrosis occurs, is 8 hours [6]. There are though case series reporting a good outcome from fasciotomies which were performed within 12 hours [11]. Impeded compartment syndrome should be recognized early, in order to avoid loss of limb function. Once the diagnosis is made, every effort should be done to decrease the intracompartmental pressure. Conservative treatment includes simple releasing of dressings or splitting a tight cast. The hand should be elevated at the level of the heart, but not above it, in order to preserve the arteriovenous gradient. Oxygen supplementation, intravenous hydration and mannitol adminstration are additional adjuvants to operative treatment [10]. Surgical decompression through fasciotomies is the mainstay of treatment, if acute compartment syndrome is suspected [3, 13].

Faciotomies of the hand are performed through four skin incision. a. Two dorsal incisions over the second and the fourth metacarpal are recommended for decompression of the interossei's and adductor pollicis' compartments. Blunt dissection is carried out deeper through the fascia between the 1st dorsal interossei and the adductor pollicis and between the dorsal and palmar interossei muscles. b. One incision radial to the first metacarpal between the glabrous and nonglabrous skin for the thenar decompression. c. One incision ulnar to the fifth metacarpal for the hypothenar release. d. Carpal tunnel, although not a true compartment, it should be released through the traditional midpalmar longitudinal incision (**Figure 6**) [2–4]. e. If digits

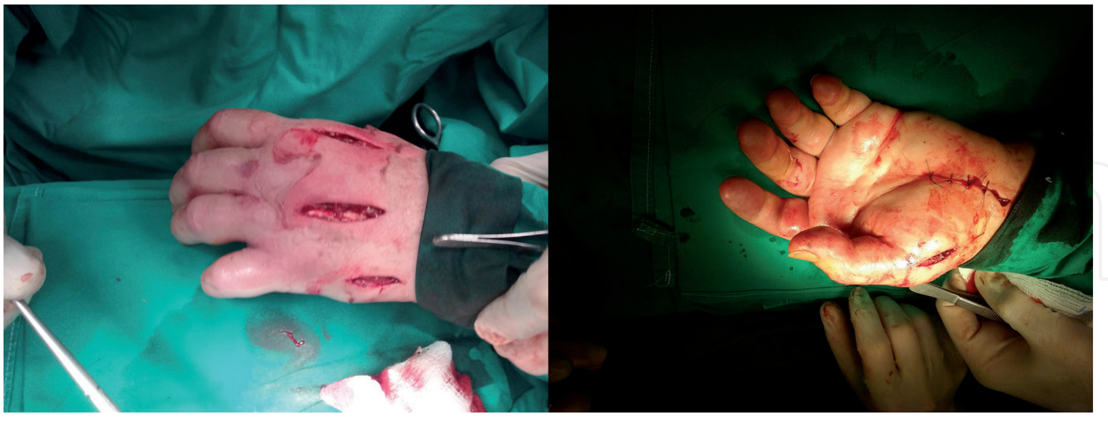

Figure 6.
Hand fasciotomies. Two dorsal incisions over the second and fourth metacarpal are used to decompress the adductor pollicis and interossei compartments. One incision radial and palmar to the first metacarpal for the thenar compartment. One incision ulnar to the fifth metacarpal for the hypothenar compartment. One midpalmar incision for carpal tunnel release. (from: Stavrakakis IM et al. hand compartment syndrome as a result of intravenous contrast extravasation. Oxf med case rep. 2018;2018(12):omy098 [8]).

Figure 7.
*Surgical decompression of index finger's compartment syndrome, due to high pressure injection injury, complicated with septic tenosynovitis of the patient of the **Figure 3**. Proper debridement required a volar Brunner incision instead of a lateral one, which is normally used for digital compartment syndrome.*

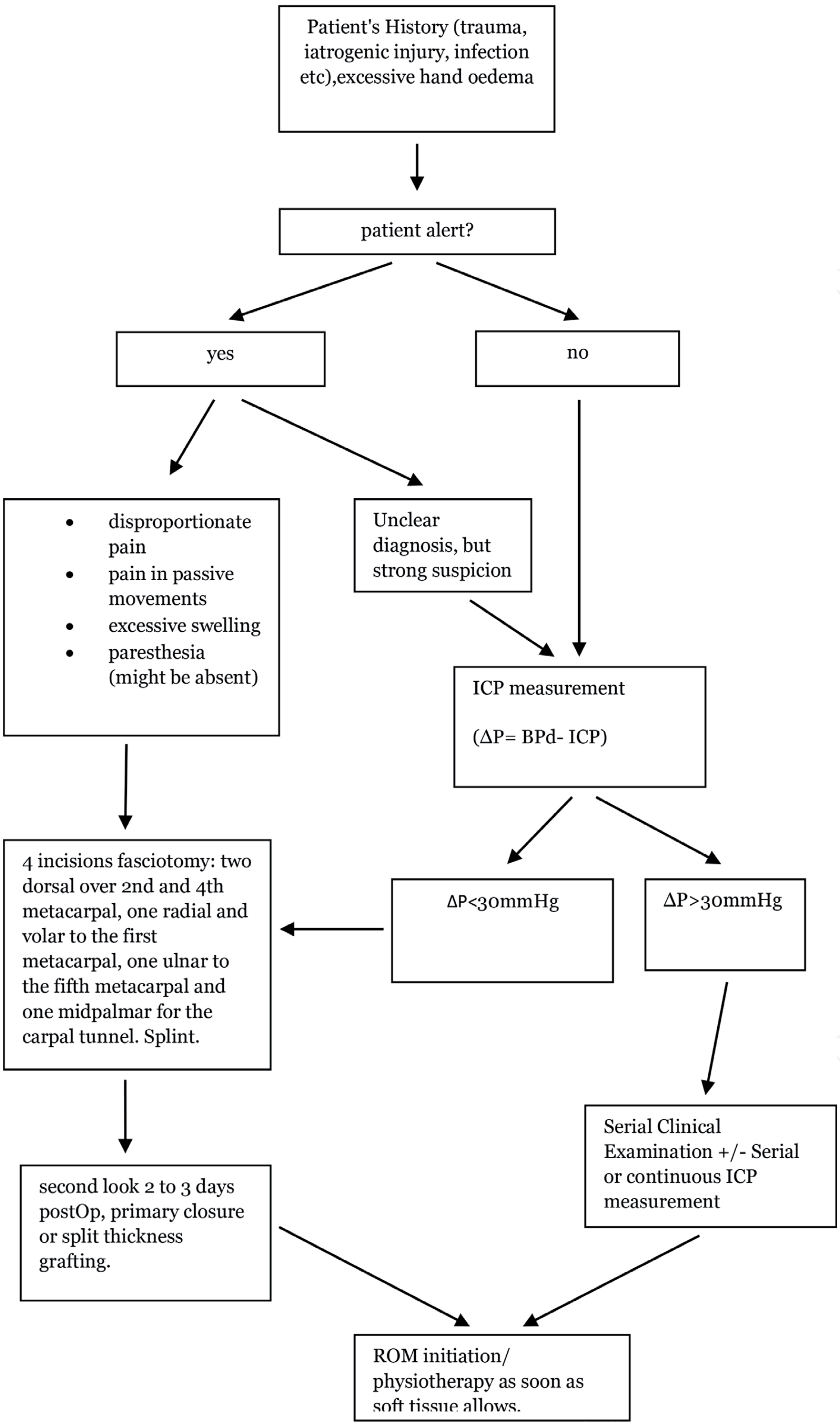

Table 2.
Algorithm of hand ACS management. ΔP: pressure difference, BPd: diastolic blood pressure, ICP: intracompartmental pressure.

are involved, Cleland and Grayson ligaments are released through midaxial lateral incision, 4 cm long centered over the proximal interphallangeal joint (PIPJ), taking care of the neurovascular bundle. Dominant sensory nerves should be avoided, indicating a radial incision for the thumb and the small finger and ulnar incision for the index, middle and ring fingers [2, 13]. In delayed cases though, especially if they are complicated with infection, a volar Brunner incision is suggested (**Figure 7**). After the procedure, the wounds are generally left opened and the hand is splinted in a safe position of function. In case of severe skin damage (burns), which precludes the splint application, the metacarpophallangeal (MTPJ) joints are pinned in flexion and the PIPJs in extension (intrinsic plus position) [2, 4]. The wounds are inspected every 2 to 3 days and a second debridement is suggested, if signs of infection or necrosis are identified. As soon as edema subsides and circulation is restored, the wounds can either be closed primarily or they can receive a split thickness graft. Priority is given to the coverage of tendons and nerves. Physiotherapy is initiated as early as possible [2, 10]. Proposed treatment algorithm of acute hand compartment syndrome is presented on the **Table 2**.

A good functional outcome can be expected after ACS, if surgical release is performed early. In case of a neglected compartment syndrome, it is widely accepted that delayed fasciotomies (more than 24 hours since initial presentation), are no beneficial to the patient, and they actually carry a risk of serious complications, such as infection, septicemia and amputation. Fasciotomies are also associated with stiffness, pain, cosmetic problems, nerve injury and chronic venous insufficiency [15, 16]. If the hand compartment syndrome is not managed properly, permanent loss of function is inevitable. Muscle contractures are developed and the hand sits in intrinsic minus position, with the MCPJs in extension and the PIPJs in flexion. Intrinsic plus contraction though is possible, if lumbricals muscles are predominantly affected. The first web space is contracted as well [2, 20].

Hand ischaemic contractures includes three groups. Group 1: All interrosei and thenar muscles are involved (typical Volkmann contracture). Group 2: thenar or interossei muscles are involved. Deformity concerns the thumb or the fingers. Group 3: one or more fingers are affected. Established intrinsic muscles contractures are treated with appropriate operative releases. The first web space is released and the tendons of the interossei muscles are released at the level of the metacarpal necks. Fibrotic tissue is removed. Detailed description of these operations are beyond the scope of this chapter [20, 21].

6. Conclusion

Hand compartment syndrome is an urgent condition which demands early recognition and treatment, otherwise it results to a permanent loss of function. Several controversies regarding diagnosis and management still exist in the contemporary literature. Future research should target on how a more accurate and early diagnosis can be achieved and the time frame beyond which fasciotomy is not beneficial to the patient. Fasciotomies of the hand are the cornerstone of treatment, and if they are performed early, they guarantee a good functional outcome. The surgeon should demonstrate a low threshold towards surgical release if compartment syndrome is suspected. Knowledge of the special anatomical features of the hand is necessary, in order for the physician to offer to the patient a sufficient treatment.

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