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PRESSURE GUIDED SURGERY OF COMPARTMENT SYNDROME OF THE LIMBS IN BURN PATIENTS

LA CHIRURGIE GUIDÉE PAR LA PRISE DE PRESSION DANS LES SYNDROMES DE LOGE DES MEMBRES CHEZ LE BRÛLÉ

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SUMMARY. Compartment syndrome is a serious complication of high voltage electrical burns, limb carbonization and deep circular burns with delayed escharotomy. Without treatment, ischemic tissue damage leads to irreversible necrosis. Treatment is emergency surgical decompression. The burned patient is usually not searchable and cannot always be readily examined because of bulky dressings; diagnosis of compartment syndrome is always hard to make. The pressure transducer used in central arterial catheters is easy available. We used it to measure pressure in muscular compartments. We measured compartment pressure three times at different depths in all cases of electrical burn, carbonization and deep circumferential burns with delayed escharotomy. We also took the pressure in the uninjured limb. The pressure assessment device was composed of a blood pressure transducer commonly used in arterial catheters for arterial pressure monitoring with three connecting branches. The first branch was connected to the 'arterial pressure exit' in the monitoring device. The second, an IV tube, was connected to one litre of physiological serum in a pressure bag inflated to 200 mmHg. The third, also an IV tube with a sterile extension cable, was directly connected to an 18G standard straight needle to be inserted in the tissues for which interstitial pressure had to be measured. In patients with thermal burns, we measured pressure before and after escharotomy. Threshold intracompartmental pressure was 35 mmHg. We carried out pressure assessment of all muscular compartments during and at the end of surgery. The pressure transducer provides a pressure value in all muscular compartments with a time of installation and measuring of less than 5 minutes. Sensitivity is measured at +/- 1 mmHg. Operation is simple, non-operator dependent, and accessible to medical and paramedic teams. The pressure transducer allows accurate diagnosis of early or established compartment syndrome. It requires no additional equipment and its application does not delay therapeutic management. Its use helps with fasciotomy decision, especially after escharotomy, guides the surgeon in the exploration of different compartments and verifies the effectiveness of surgery.

Keywords: burns, compartment syndrome**,** limb**,** pressure

RÉSUMÉ. *Le syndrome de loge est une complication sévère des brûlures électriques de haut voltage, les carbonisations de membres et les brûlures profondes circulaires en attente d'escarrotomie. Sans traitement, les lésions tissulaires ischémiques apparaissent et entrainent des lésions nécrotiques irréversibles. Le traitement est la décompression chirurgicale d'urgence. Le brûlé est généralement in interrogeable et le diagnostic est toujours difficile à établir étant donné les volumineux pansements. Le capteur de pression au moyen de cathéters artériels est facile et nous l'utilisons pour mesurer la pression dans les loges musculaires. Nous mesurons cette pression compartimentale à 3 reprises à des profondeurs différentes, dans tous les cas de brûlures électriques avec carbonisation et brûlures circonférentielles profondes et qui sont en attente d'escarrotomie: nous prenons également la pression au niveau des membres non atteints. L'appareil de mesure est composé d'un capteur de pression sanguine, avec trois connexions: la première est la pression artérielle habituelle, la deuxième est en rapport avec 1 litre de sérum dans une poche gonflée à 200 mm Hg, la troisième est directement en rapport avec une aiguille 18 G pour être insérée au niveau des loges musculaires. Chez les patients porteurs de brûlures thermiques, la pression est prise avant et après l'escarrotomie. Le niveau de pression intra compartimentale est de 35 mm d'Hg. Nous évaluons la pression dans toutes les loges pendant la chirurgie et à la fin de l'intervention. Le capteur permet d'évaluer la pression dans tous les compartiments musculaires en moins de cinq minutes, avec un degré de fiabilité de plus ou moins 1mm Hg. L'opération est simple, non opérateur dépendant et accessible aux médecins et aux paramédicaux. Le capteur de pression permet le diagnostic précoce du syndrome de loge. Il ne nécessite pas un équipement additionnel et son usage ne retarde pas le début de la thérapeutique. Il aide à la décision de fasciotomie, spécialement après escarrotomie, guide le chirurgien dans l'exploration des différentes loges et vérifie l'efficacité de la chirurgie.*

Mots-clés: *brûlures, syndrome de loges, membres, pression*

Introduction

Compartment syndrome is defined by increased tissue pressure inside an osteoaponeurotic compartment at normal muscle tension. Normal intramuscular compartment pressure ranges from 0 to 10 mmHg.[1] Tissue pressure may be elevated by internal expansion

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forces, which can be caused by various conditions including but not limited to lower limb fractures, arterial trauma, thrombophlebitis and burns. In limb burns, local loss of capillary vessels in the burnt skin and excessive fluid resuscitation can cause edema. The small arterioles that provide blood circulation in the muscles may then be occluded. Because the pressure is much lower than the patient's systolic blood pressure, muscles may be ischemic with necrosis for some time before pulses in the distal arteries disappear.[2]

In burn patients, compartment syndrome is a possible complication following two types of burns: high-voltage electrical burns (*Fig. 1*) and very deep third-degree burns (*Fig. 2*). In both conditions, direct muscle damage occurs as intramuscular edema develops, and is followed by increased interstitial pressure.

In deep circular burns, escharotomy (*Fig. 3*) must be performed on admission to prevent or block the 'external tourniquet' phenomenon caused by the inability of deeply burned skin to expand. Without escharotomy, the circumferential eschar impedes the development of edema and increases interstitial pressure, thus leading to compartment syndrome, as in the first two situations.

Elevated intracompartmental pressure obstructs venous drainage, which is an independent factor promoting edema. A vicious circle leads to compression of the arteriolar ends of the capillary beds. Ischemic tissue damage rapidly results, and leads to irreversible necrotic lesions if surgical decompression does not occur within the first 6 hours.[3-4] Its sequelae can be devastating and may include renal damage with myoglobinuria, ischemic contracture and muscular shrinkage, neurological damage with paralysis and paresthesia, and even amputation after gangrene in cases of missed diagnosis.[4]

Emergency surgical decompression must be performed: a fasciotomy of the affected muscle compartment. It is important to stress that in deep circular burns without signs of carbonization and thermal damage to the muscles, early skin incision (escharotomy) can prevent the occurrence of compartment syndrome.[5]

Three aspects of compartment syndrome in the burn patient present challenges to medical staff. First of all, compartment syndrome is hard to recognize. Patients who are sedated, intubated and in severe pain due to burn wounds cannot easily notice or report its clinical signs. Severe inflammation can mask symptoms,[6] and burns are accompanied by substantial edema that tends to be even greater in larger burns. Moreover, swelling increases with excessive fluid resuscitation, further compromising microcirculation in the muscle compartment.

Secondly, it is extremely difficult to assess the severity of compartment syndrome. Third- and fourth-degree burned skin with cutaneous retraction can simulate muscular shrinking.

Thirdly, although the effect of surgical decompression can be subjectively assessed by muscle compartment flexibility, no objective criteria have been used to assess this procedure in severely burned limbs. There are reports of incomplete escharotomy that might have been corrected much earlier if objective pressure assessment had been used.[7] Later, necrosis can occur if fasciotomy is incomplete. Furthermore, in electrical burns, progressive muscle damage is frequent, even when the muscle appears viable on first exploration.[8]

Several techniques in the literature make it possible to assess pressure in trauma situations.[9] In burn patients, extremity perfusion is monitored by two main methods: assessment (of the absence) of pulses by Doppler ultrasound and direct measurement of intramuscular pressure. Findings that peripheral pulses are preserved for quite a while despite markedly diminished muscle blood flow suggest that decompression based on the absence of Doppler pulses may be performed too late.[10]

We therefore used a pressure transducer or 'pressure head' to measure pressure, to assess severity, to guide surgery, and to evaluate its results (i.e., whether tissue pressure returned to normal).

This study reports our experience of using non-continuous pressure assessment of the limbs in burn patients.

Fig. 1 - Palm hand electrical burn, entry electrical current.

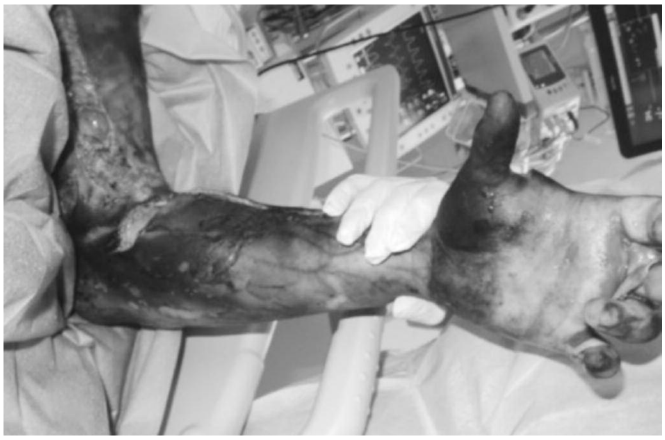

Fig. 2 - Carbonization of left upper limb.

Fig. 3 - Deep circular burn with delayed escharotomy.

Methodology

Our institutional review committee reviewed and approved this research project. This approval covers the entire period of the overall study, including subsequent stages.

The pressure assessment device (commonly used in arterial catheters for arterial pressure monitoring) was a blood pressure transducer with three connecting branches. The first was connected to the 'arterial pressure exit' in the monitoring device. The second, an IV tube, was connected to one litre of physiological serum in a pressure bag inflated to 200 mmHg. The third, also an IV tube with a sterile extension cable, was directly connected to an 18 G standard straight needle. We opened the stopcock in the pressure transducer to inject serum into the entire system and tare it to the 'zero arterial pressure function' in the monitoring device. Finally, we set the maximum pressure at 60 mmHg (*Fig. 4*).

The threshold pressure was 35 mmHg, which is the normal intracapillary pressure. Localized hypoperfusion appears before arteriolar flow is compromised.[10] Above this pressure, ischemic damage appears. When the pressure was below the threshold, we subtracted diastolic from intracompartmental pressure to check when the differential was lower than 30 mmHg.[11] If so, we performed fasciotomies.

The study took place from December 2012 through November 2013. Patients transferred to our centre with electrical burn on the limbs, very deep third-degree burns with signs of limb carbonization, or deep circular burns with limb tightness at palpation met the inclusion criteria, which were assessed at admission. The study included 12 patients: 10 with thermal burns and 2 with electrical burns.

The protocol for assessing compartment pressure called for measurements to be made in patients with electrical burns on the limbs before any surgery in any compartment. If fasciotomy was indicated, we measured the pressure in all muscle compartments at the end of the operation to ensure the surgery had been effective. In patients with thermal burns, we measured compartment pressure before and after escharotomy. If escharotomy reduced the pressure below 35 mmHg, we stopped surgery; during the initial period of increasing edema, pressure was measured at least once daily if clinical and/or laboratory signs of compartment pressure appeared. If pressure was higher than threshold pressure, we performed a fasciotomy and explored the affected compartments.

All measurements were performed three times at different depths in the muscle zone, and mean pressures were calculated to minimize the standard deviation. We also measured the pressure in the matching compartments of the uninjured limb as a control and to increase the specificity of the measurements.

Results

It was simple to connect the pressure transducer line to the normal intensive care monitoring device. The average assembly time was five minutes for both medical and paramedic teams. Pressure was checked within a sensitivity of 1 mmHg. All undamaged limb intracompartmental pressure assessments were within normal ranges.

The total cost of constructing the device was 6 euros, which allays any concerns about its cost-effectiveness ratio.

Among the 10 patients with thermal burns, one had a 95% Total Body Surface (TBS) burn, including fourth-degree burns on all limbs. The other nine patients had deep circular limb burns: six on the forearms and three on the legs. All nine underwent escharotomy to release external compression. After this procedure, pressure returned to within normal range for seven patients. Compartment syndrome was found in patients 7 and 9, one in the legs and the other in the anterior forearm. For each of these two patients, this initial escharotomy was performed respectively at 18 and 21 hours after the deep circular burn and one hour after admission. Subsequently fasciotomies were performed with pressure measurements providing guidance for decompression of the muscle compartment. Normal pressure range was achieved after the procedure. No necrotic tissue was found and ischemic muscle coloration rapidly returned to normal.

Fig. 4 - Pressure assessment device with blood pressure transducer and two IV tubes for back-pressure bag and measure straight needle.

The patient with signs of carbonization on four limbs was admitted to an operating room three hours after the burn for pressure assessment. All pressure measurements were superior to threshold. Escharotomies of the arms, forearms, thighs and legs were performed. After this first surgical procedure, all intracompartmental pressure assessments except for the thigh remained higher than 35 mmHg. Fasciotomies were carried out immediately before skin and muscle necrosis excision. Postoperative pressure evaluation was within normal range for all muscle compartments.

These 10 patients (one carbonization and nine deep circular burns) were divided into two groups. The first included the seven patients with normal pressure after escharotomy alone. Group 2 included the three patients who required fasciotomy after the initial escharotomy.

A third group included the two patients with high-voltage electrical burns: one with damage to the right forearm and leg with third-degree burns on the dorsal foot and hand. The other patient had burns to all four limbs with third-degree burns on the left leg. Both had mean intracompartmental pressure in both sets of limbs greater than 35 mmHg. Fasciotomies began for both in the superficial anterior forearm compartment. When intraoperative assessment showed patient 1 had high pressure in the deep anterior forearm compartment, a complementary fasciotomy was performed. The carpal tunnel was always opened. No fasciotomy of the posterior forearm compartment was performed for patient 2, because the average pressure remained below the threshold. Necrotic muscle tissue was removed from the deep anterior compartment.

For the lower limb burns showing signs that high-voltage current had passed through, four leg compartments were opened. Ischemic muscle tissue was found in the anterior space and removed. The tarsal tunnel was always opened because of the risk of neurological compression by edema in an inelastic space. Intraoperative measurement of pressure in the intermetatarsal compartment showed excessive pressure for both patients. Fasciotomies were performed at the tops of the second and fourth metatarsals. No signs were found of ischemic tissue. Post-fasciotomy assessment showed average pressure below 15 mmHg in each injured limb.

The patients with high-voltage electrical burns both underwent a surgical second look at 48-72 hours after injury to check for later muscle necrosis; none was found.

The patient with carbonization of limbs and 95% TBS burns died after 15 days of intensive care. All the other patients survived.

Clinical examination of the nine surviving thermal burn patients at six months showed no sensory or motor neurological deficit. The absence of neurological abnormalities or contractures at this follow-up visit in the seven patients without excess pressure in the acute phase after escharotomy showed that there were no false negatives in this group.

A neurological assessment of upper limbs that underwent broad excision of nerves and muscles was not performed for the patients with electrical burns. An assessment of limbs with compartment syndrome before fasciotomy and without broad tissue damage found no neurological deficits. No amputations were done.

Fig. 5 - Intracompartmental measurement with 18G straight needle in deep circular burn.

Fig. 6 - Monitoring device showing a 47 mmhg intracompartmental pressure.

Discussion

Compartment syndrome is a serious complication in which early diagnosis is the key for optimal management by surgical decompression. It is difficult, however, to collect clinical signs and symptoms from burn patients, mainly because of their high levels of both pain and sedation.

Obtunded consciousness is very common in these patients, and none of the subjective signs are reliable. Swelling and palpable tightness are the first signs of compartment syndrome and frequently the only ones.[5] Spontaneous flexion of the digits can be seen when compartment syndrome has been underway for a few hours and signs of muscle ischemia are observed.

Some clinical findings are also unreliable in burn patients with a normal state of consciousness. Pain may be due to various causes, including especially the burns themselves and a severe reaction to inflammation. Paresthesia and paresis may arise secondary to muscle ischemia or be the direct consequence of an electrical burn.

Finally, voluminous edema, which can arise gradually and may be considerable with fluid resuscitation, can promote elevated interstitial pressure and compartment syndrome.[1]

We therefore evaluated the utility of pressure assessment in patients with burned limbs. The initial assessment served as a rapid diagnostic test that did not delay surgery. Our pressure-monitoring device with an arterial transducer was available within five minutes. The ease and availability of the device make the test usable after a short training session for both medical and paramedic personnel.[10]

Specificity was good with normal pressure in healthy limbs. Using a simple needle can be the cause of false positive results due to surrounding soft tissue or contact with bone structure. Consequently, for each assessment we measured pressure two or three times in the same area but at different depths with the needle perpendicular to the skin, and recorded the mean value to avoid false positives. We also tested a side-port needle, as described in the article by Boody et al.,[12] to avoid needle obstruction. We noted no difference between the 3 consecutive patients.

Pressure assessment is extremely useful in electrical burns, as clinical findings are often normal. Compartment syndrome is very common in this type of burn. Diagnosis may be doubtful in situations where clinical signs are not discernible or have not yet appeared. Early diagnosis makes it possible to avoid another source of muscular necrosis and decrease morbidity. Pressure assessment does not, however, test tissue viability, and secondary muscle exploration is always necessary to find initially viable necrotic muscles. Pressure assessment treats the consequences of muscle necrosis, but further surgery is needed to remove necrotic tissue.

For fourth-degree burns and deep circular burns with delayed escharotomy, pressure assessment provides substantial and objective aid in determining whether pressure is elevated after escharotomy. In the three cases in which it remained high after the cutaneous incision, no evident clinical findings showed compartment syndrome (*Figs. 5-8*). There was one doubtful situation in which the pressure assessment was extremely helpful. Pressure assessment may also make it possible to avoid opening a muscle compartment in doubtful cases after

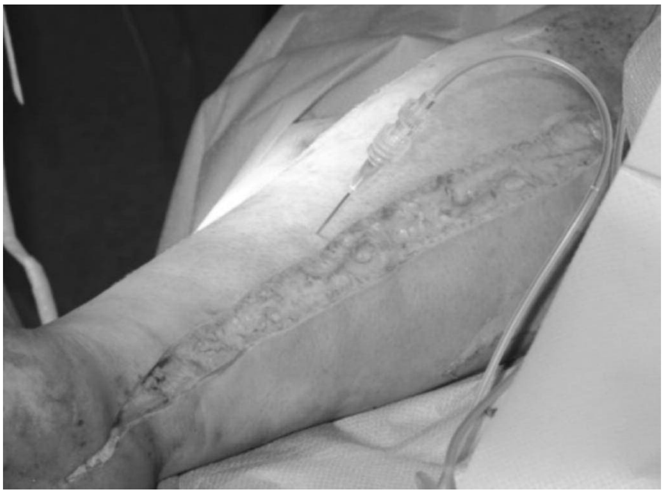

Fig. 7 - Efficacy assessment of intracompartmental limb decompression after escharotomy.

Fig. 8 - Monitoring device showing 40 mmhg pressure persistence after escharotomy.

incision of the burned skin. Pressure assessment was repeated every six hours during the period of major fluid resuscitation to avoid late compartment syndrome.

In terms of surgery, the device provided very specific indications to open deep muscle compartments that would have remained closed without pressure monitoring.

Compartment pressure assessment with a pressure transducer, an arterial line manometer, and a straight 18G needle was included in our initial clinical evaluation of burn patients with deep circular limb burns with delayed escharotomy, fourth-degree limb burns or electrical burns. This evaluation provided an objective answer about compartment pressure in situations where clinical signs were unclear; it guided the decision about fasciotomy and improved monitoring. These measurements were sensitive, specific and inexpensive.

Escharotomy was effective in preventing compartment syndrome in deep circular burns, although the decision remains difficult when based on clinical evaluation alone, when it depends strongly on the surgeon's experience.

We have begun a prospective study to attempt to identify a subcutaneous pressure threshold that can improve decisions about escharotomy. Our ultimate aim is to create a decision tree for limb burns at risk of compartment syndrome.

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