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Research Article

Tibial Fractures Complicated with Compartment Syndrome – Clinical and Histological Aspects

Cristina Patru[2], Alexandru Lisias Dimitriu[1,2]*, Nicolae Marian Ciurea[2], Prodan Alina Mihaela[3], Dragos Ene[1,3] and Razvan Ene[1,2]

[1]Carol Davila University of Medicine and Pharmacy, Bucharest, Romania

[2]Department of Orthopedics and Trauma, Clinical Emergency Hospital, Bucharest, Bucharest, Romania

[3]Department of Surgery, Clinical Emergency Hospital, Bucharest, Romania, Bucharest, Romania

***Corresponding Author:** Alexandru Lisias Dimitriu, Carol Davila University of Medicine and Pharmacy, Bucharest, Romania.

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Abstract

Fracture of the tibia is one of the most common long-bone fracture worldwide. One of the most serious complications of tibial fractures is considered the acute compartment syndrome (ACS). If this complication is not treated it in time can lead to irreversible complications, like limb amputation, renal failure or even death. We found that clinical and histological aspects are essential for early diagnosis in CS; in case of suspicion, ICP can be measured, but the clinical symptoms and histologic exam are crucial. Increased consistency of muscular compartments is the central clinical feature of CS and, once detected, it must immediately raise the suspicion of CS; failure to do that can delay the diagnosis and, thus, proper treatment even until the injuries become irreversible.

The disturbances characteristic for CS affects primarily the microcirculation, so arterial pulse is present until the late stages of CS; that is why the presence of arterial peripheral pulse does not exclude the diagnosis of CS.

Histological evaluation confirmed the reaction to high ICP (ischemia): ballooning of the muscle fiber, erasure of the striated, myofibrillar structure, with homogenization of the sarcoplasm, centralization of striated muscle fiber nuclei; (nuclei leave the periphery/sarcolemma and gather towards the center of the striated muscle fiber).

In our study, we tried to find correlations of factors that can predispose to the development of compartment syndrome. Treatment of CS consists of any measure to decrease ICP; decompressive fasciotomy when CS is installed must be performed early and by a large incision, which must open all the muscular - compartments on all their length; otherwise, the remaining fascial structures act like tourniquet and the muscles will herniate and become necrotic. If bone stabilization is necessary, it will be performed avoiding any method which increase ICP, especially reaming. Post- operative local and general monitoring of the patient should address to all the possible.

Keywords: Compartment Syndrome (CS); Polytrauma; Fasciotomy; Tibial Fracture; Intracompartmental Pressure (ICP)

Introduction

Because of its subcutaneous location, the tibial fracture is a very common orthopedic injury, that usually requires surgical management [1]. Because of its relation to the calf muscular lodges, CS is a possible complication, that can have catastrophic consequences if it's left untreated, or if the time elapsed from the initial trauma to the arrival at the Emergency Orthopedic Department is too long [1].

We should mention that compartment syndrome is not an orthopedic trauma specific entity, and can appear in any inextensible compartment - such as peritoneum [2], only that is more frequently encountered in trauma of the limbs.

Not all tibial fractures complicate with CS, so the aim of this study is to identify the elements that can lead to this potential complication.

The complications that can be derived from compartment syndrome are sometimes irreversible and life threating, like acute renal failure, limb amputation or even death.

In the present study, we wanted to find factors that can predispose patients to this complication, in order to improve the outcome and avoid life threating conditions.

The treatment of this severe complication is multimodal and multi-disciplinary, the key elements being the surgical management and the post-operative treatment. An important role consists of postoperative analgesia, co-administration of i.v. non-steroid anti-inflammatory drugs, seriously decreases the inflammatory response to the surgical stress [3].

Materials and Methods

In this study, we analyzed 138 patients that were admitted and treated in the Orthopedics Department of the Clinical Emergency Hospital of Bucharest, Romania, between 01.02.2023 – 31.12.2023. Because we wanted to see which are the predisposing factors that can lead to compartment syndrome, we looked at the location of the tibial fracture. The tibial fractures were divided in proximal fractures, middle third fractures and distal fractures. Others factors that were evaluated included the age and gender of the patients, the mechanism of injury, that was divided in crushing injury, motor vehicle accident, pedestrian injury and falls, and the choice of osteosynthesis (IM nails, plates, screws and external fixation). The choice of fixations was made accordingly to the level of the fracture, the comminution, open vs closed fractures, and to the soft tissue lesions.

We excluded open fractures that required vascular surgery also, minor patients <18 years old, non-compliant patients or patients that were managed non-surgically.

Although the diagnosis of compartment syndrome is based on the clinical aspect, measurements of ICP were also made.

Local exam of the shank included both subjective (those declared by the patient) and the objective (those diagnosed by the examiner) elements.

Subjective elements — were:

Pain - has two components [4]:

- Fixed, localized in the medium third of the diaphysis, on the anterior and external aspect of the shank, corresponding to a deformation of the shank at this level
- Diffuse pain, situated in the posterior part of the shank, corresponding to the posterior muscles
- Low intensity numbness of the toes
- Tension - together with the pain, the patient describes an increasing sensation of tension in the posterior part of the shank
- Functional impairment- the patient describes that he cannot elevate the foot form the bed, although he can do that movement with the knee, flexion and extension of the foot are possible, but active dorsi—flexion is limited due to pain

Objective elements — were:

Inspection that can reveal:

- The existence of wounds of the shank, corresponding to the initial trauma
- Bruises on the anterior, internal and external aspects of the shank
- Deformation of the shank, with angulation

- Obvious increase of the dimensions of the shank, by comparing with the contralateral side

Figure 1: Clinical aspect of a tibial fracture complicated with CS, with a small wound that communicates with the fracture site.

Palpation and passive movements

- On the anterior surface, discontinuity of the tibial crest and osseous crepitating
- Abnormal movements at the same level (which were tested by very gentle maneuvers, so as not to enhance the post-traumatic injuries)
- Palpation of the posterior muscles of the shank that can reveal increased consistency of these muscles in the same region where the patient describes the tension
- The posterior pain is increased by the passive dorsiflexion of the foot, but the anterior one is decreased by gentle traction

Measurements

- Increased circumference of the left shank compared to the right especially in the proximal two thirds
- Shortening of the leg, expressed by the difference between the distance between the ASIS and the tip of the internal malleolus between left-right side; since the distance between the ASIS and the base of the patella is the same, that means that shortening is in the tibial area; indeed, the distance between the inferior pole of the patella and the tip of the internal malleolus is smaller on the affected side, thus explaining the global shortening.

Vascular and nervous examination:

- Pulse can be present and symmetric on the popliteal, anterior and posterior tibial arteries or absent
- Capillary refill can be slightly deficient on the affected side
- In early stages of CS paralysis is not detected, active movements of the toes are possible
- Distal numbness (discrete) on the toes and plantar surface, as well as a slight sensitive asymmetry with the right side when the plantar face of the toes was touched, can be found.

It is to be underlined that the presence of the pulse, as said, does not exclude the CS, it just indicates that the pathophysiological processes generating API have not yet installed, so that CS is NOT in the irreversible stage [5].

In order to perform the positive diagnosis, there are two things to be demonstrated: the fracture and the CS. For the fracture, the standard set of X-rays include the knee, the shank and the ankle, that were performed both in AP and lateral view (Figure 2), revealing the fracture site level, if there is any comminution, and the displacement degree.

Figure 2: AP and lateral view of a middle third comminuted tibia and peroneal fracture.

As for the CS, the diagnosis is established based on the clinical symptoms, but, whenever it is possible, the ICP should be measured in order to establish the stage of the CS, and thus, the treatment [6].

A discussion is necessary here, regarding the diagnosis of CS: the value of the ICP precisely indicating the diagnosis of CS is controversial in literature, two different opinions being formulated:

- The first one, which considers the value of 30 mmHg as the border value above which CS is diagnosed, and The second one, considering not the absolute value of the ICP as the criteria for diagnosing CS, but the difference between the diastolic pressure and the ICP, called the differential pressure. If the differential pressure is less than 20 mm Hg, CS iS diagnosed. This theory respects the individual variations of ICP due to the circulatory regimen of each patient. In hypertensive subjects, it is normal for the ICP to be higher than in normotensive, so this theory seems to be more flexible and comprehensive than the one which establishes a fix value, regardless of the variations of ICP due to the variations of blood pressure, pre-existing to trauma.

Differential diagnosis is to be established with:

- Simple contusion
- Deep Venous Thrombosis
- Infections
- Chronic Venous Insufficiency
- Cellulites of the shank
- Erysipelas
- Tumors

Obviously, these cases need a sort of bone stabilization method. The most used method of fixing the diaphyseal fractures of the tibia is by using an IM nail, that can be mounted either by reaming or non-reaming technique, in accordance with the local aspect of the fracture, the size of the IM canal, and associated chest injury that can increase the risk of respiratory distress. During bone stabilization, the status of the compartments was continuously monitored, so as not to increase the ICP; the reduction and stabilization maneuvers should be gently performed.

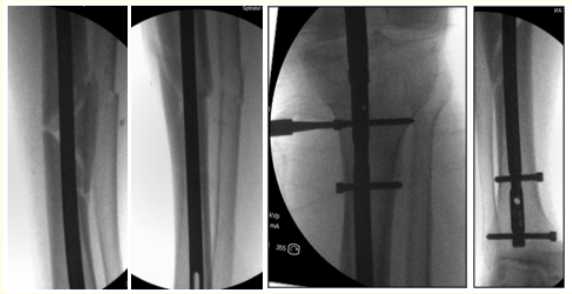

Figure 3: Bone stabilization using a IM unreamed nail.

When fasciotomy was needed, when two or more compartments were affected by CS, the approach was internal and external - an incision on the medial aspect of the shank, from the knee to the malleolus, parallel with the posterior tibial border, at approx. 2 cm from it, so as to recline anteriorly the saphenous vein and the nerve, and also an external large incision, in order to make sure that all muscle lodges were explored.

Figure 4: Fasciotomy of the shank with wound dehiscence immediately after incision.

Post-operative treatment consisted of:

- Elastic bandage on the operated side and elastic compressive stocking on the other
- Elevated position of the operated leg
- Treatment was completed with: antibioprophylaxy; anti-inflammatory (non-steroidal) medication, anti-thrombotic treatment with LMWH.

Results

A total of 143 tibial fractures were admitted and treated in the mentioned period, because five patients had bilateral fractures of the tibia. We registered 39 fractures of the proximal third (27.27%), 68 fractures of the middle third (47.55%) and 36 fractures of the distal third (25.18%).

Regarding the age and of the patients who developed compartment syndrome, we are looking at young patients with a mean age of 33.2 years old ±12.2 SD by comparing with the patients that did not register this complication 42.5 ±13.3 SD.

The compartment syndrome appeared as a complication that required specific surgery the most frequently in the middle third fracture group, 8 cases were registered with this complication (11.76% $p < 0.05$), followed by 3 cases in the proximal fracture group (7.69%), and 1 case in the distal fracture group (2.77%). The only statistical significance regarding the occurrence of compartment syndrome was found to be in direct relationship to fractures of the tibia that occurred in the middle third group.

Considering the cases that developed compartment syndrome within the middle third fracture group, we also found out that out of the 8 cases that developed this complication, 6 of them were comminuted fractures. Although we cannot say that this is a predisposing factor, because of the relatively few cases, it is something to keep in mind, that in cases with severe comminution that usually result from high energy trauma there is a higher chance to develop an increase intercompartmental pressure that can lead to compartment syndrome, due to excessive bleeding.

Another factor that was analyzed in our study, was the mechanism of injury. Out of the total cases that developed compartment syndrome (12 cases), 5 were due to crushing injuries, 4 were due to either motor vehicle or motorcycle accidents, and 3 were pedestrian that were struck by cars while crossing the street. We noticed that none of the cases were due to simple falls, which supports the remark that high energy trauma that produces comminutive fractures and also important soft tissue lesions are more prone to develop important complications like compartment syndrome.

The patients that developed compartment syndrome on which we performed fasciotomy, after exploration of the muscle lodges, we took muscle samples from the muscles that were not contracting with electrical or mechanical stimulation, for histology examination.

The histological aspect was considered to be typical for ischemia in different stages, accordingly to the stage of CS.

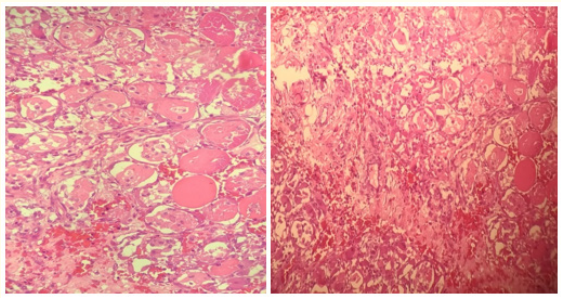

Figure 5: Secondary (ischemic) pathological changes (reactions) of the striated muscle.

- Ballooning of the muscle fiber
- Erasure of the striated, myofibrillar structure, with homogenization of the sarcoplasm (non-uniform eosinophilic aspect, varied in intensity);
- Centralization of striated muscle fiber nuclei; (nuclei leave the periphery / sarcolemma and gather towards the center of the striated muscle fiber).
- Caryolysis (loss, erasure of the chromatin pattern of the nuclei) karyorexia (fragmentation, dissolution, disappearance of the nuclei)
- Fragmentation, retraction, sarcolemma (cytoplasm of striated muscle fiber) which may contain fragments of nuclei that show the changes described above);
- Persistence of the basement membranes that is a frame (network) that is the "basis" of a future, possible muscle regeneration;
- Interstitial edema; interstitial hemorrhage; interstitial and perivascular fibrosis (depending on the age of the process);

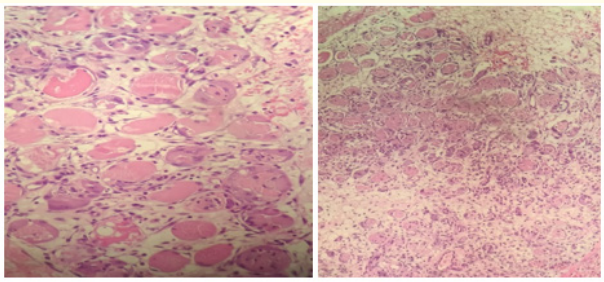

Figure 6

- Mononuclear inflammation predominantly perivascular and interstitial;
- Macrophages (histiocytes) present in the necrotic muscle fibers (myolysis) or in the fragments of the sarcolemma with remains (nuclear debris) that have as role the phagocytosis of the necrotic elements. This can also be found as an reaction to orthopedic metallic materials, but at a different mechanism. In those cases, the macrophages try to limit the spread of foreign body, thus creating the foreign body giant cells [7-9]
- Temptation of regeneration - on the support formed by the sarcolemma. Remaining, against the background of muscle fiber necrosis (see picture 5f): cytoplasm (sarcolemma appears basophilic, nuclei are vesicular, nucleated approximately the appearance of myoblasts.
- Repeats fusiform elements that fuse to form multinucleated elements (sarcoblasts)

Discussion

The presented study shows that communitive fractures of the middle third of the tibia that usually derives from a high energy trauma are in direct relationship with the development of compartment syndrome. By looking at the specific literature regarding this subject, we noticed that Park., *et al*. [10] found a similar relationship in his study. He analyzed more patients with tibial fractures (414 cases), and found also a relationship between middle third fracture of the tibia and compartment syndrome developed as a complication, registering a rate of 8.1%, which is slightly lower that the rate discovered by our clinic. However, he did not analyze the aspect of comminution, but looked into the mechanism of injury, but in his study this element was not found to be significantly associated with the development of compartment syndrome. An interesting discovery made by Park., *et al*. [10] was that the mean arterial pressures upon admission of the cases with compartment syndrome was higher (107 vs 98.5 mmHg), probably in direct relation with the bleeding cause by the injury.

A special thing to be discussed is the indication for thrombo-prophylaxis in these cases. Although someone might think that, due to the open fasciotomy, the risk of bleeding would be induced by LMWH; this aspect is overwhelmed by the considerable thrombotic risk of CS complicating a tibial fracture. Usually, thrombo-prophylaxis is recommended until the patient is not at rest anymore, but there is no consensus upon the precise time delimitation of the rest time in tibial fractures. But, compared to an uncomplicated tibial fracture, these cases have a supplementary pro-thrombotic factor risk - the compartment syndrome. As it is known, CS is characterized. by disturbances of the microcirculation, due to increased ICP, which compresses the capillaries, thus inducing stasis and thrombosis. Compared with Deep Venous Thrombosis, where thrombi obliterate the medium and large veins, CS acts on the very small vessels, so, if these become thrombotic, the process extends centripetally, to medium and then large veins.

But, unlikely DVT, where thrombi can be destroyed by anti-coagulants, the thrombotic microcirculation cannot be accessed by heparin or other anticoagulants, thus making thrombotic microcirculation a practically impenetrable territory to heparin and derived products, and, in the same time, the initiator of extensive capillary thrombosis, which irreversibly compromises the circulation of the affected limb, because it extends not only to the veins, but to the arteries as well.

For these reasons, thrombo-prophylaxis after CS is particularly important and, in these cases, the duration was extended to 4 weeks after trauma.

The increased risk of thrombotic complications like deep vein thrombosis or pulmonary embolism in patients that developed compartment syndrome after lower limb fractures, was also proved by the study of Yang., *et al*. [11], that analyzed the data of a total of 110 patients. All of the patients with compartment syndrome received chemoprophylactic DVT prophylaxis in the form of low-molecular-weight heparin sodium (LMWH), and also

mechanical prophylaxis was performed by the use of a pneumatic compression device (with caution, as excessive pressure on the affected limb could exacerbate the compartment syndrome). Even in this situation, Yang., *et al*. [11] still registered a rate of 23.6% of deep vein thrombosis complication.

The increased risk of thrombotic complications was also shows by Lupescu., *et al*. [12], but in femoral fractures in polytrauma patients, in which the main mechanism seems to be the systemic inflammatory response syndrome, which is not a known characteristic feature in compartment syndrome. More studies are needed in order to evaluate other mechanisms that increase the risk of thrombotic complications in compartment syndrome, other than the alteration of the microcirculation.

Conclusions

- Compartment syndrome is a serious life-threatening orthopedic emergency that needs to be treated rapidly in order to avoid complications, like limb amputation, acute renal failure or even death.
- In our study, we found a direct correlation between middle third comminutive fractures of the tibia, that results from high energy trauma and the development of compartment syndrome.
- Clinical aspect is essential for early diagnosis in CS; in case of suspicion, ICP can be measured, but the clinical symptoms and signs are crucial
- Increased consistency of muscular compartments is the central clinical feature of CS and, once detected, it must immediately raise the suspicion of CS; failure to do that can delay the diagnosis and, thus, proper treatment even until the injuries become irreversible
- The disturbances characteristic for CS affect primarily the microcirculation, so arterial pulse is present until the late stages of CS; that is why the presence of arterial peripheral pulse does not exclude the diagnosis of CS
- Treatment of CS consists of any measure to decrease ICP; decompressive fasciotomy when CS is installed must be performed early and by a large incision, which must open all the muscular - compartments on all their length; otherwise, the remaining fascial structures act like tourniquet and the muscles will herniate and become necrotic
- If bone stabilization is necessary, it will be performed avoiding any method which increase ICP, especially reaming
- Post-operative local and general monitoring of the patient should address to all the possible complications of rhabdomyolysis, which characterizes CS.

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