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The Association between Clinical Features and Measurements of Intra-Compartmental Pressure in Diagnosis of Acute Compartment Syndrome of Closed Leg Fractures

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Abstract

Objective: To find the clinical features of compartment syndrome and measurement of intra-compartmental pressure (ICP) in early diagnosis of the compartment syndrome of different types of closed leg bone fractures and their association with the severity of the fracture. ***Methodology:*** This prospective study included 20 patients with unilaterally closed fractures of the tibia and/or fibular fracture that presented to Shar Hospital, Sulaimaniyah City, Northern Iraq, from October 1st, 2018, to July 1st, 2020. Sociodemographic information with date and mechanism of injury, severity, side, and site of a fractured leg, and fracture's type according to Oestern and Tscherne classification of the close fracture were obtained. ICP was measured in the broken leg and normal leg at the time of admission to the emergency ward for patients using the needle-infusion technique (Whiteside's technique). ***Results:*** All patients were followed clinically by looking at features of the compartment for three days before the definitive treatment was established. We found that 8 out of 20 patients were complaining of severe, unusual pain (paresthesia) during follow-up. Acute compartment syndrome (ACS) was diagnosed in 1 (55-year-old man) out of 8 patients whose clinical features of compartment syndrome built up and with the differential pressure (Δp) of <30 mmHg. The cause of his fracture was a road traffic accident (RTA), and he underwent a fasciotomy. At the same time, the rest of the patients had no features of the compartment. ***Conclusions:*** We revealed a significant clinical correlation between the measurement of ICP and early detection and diagnosis of the post-traumatic ACS of the leg, and the measurement of ICP was valuable in the diagnosis of ACS and as a criterion for decompression. Also, this study shows a positive correlation between the type of fracture according to the Oestern and Tscherne classification and the increase in the measurement of the ICP.

Introduction

Compartment syndrome (CS) is a limb-threatening and life-threatening condition observed when perfusion pressure falls below tissue pressure in a closed anatomic space. There were many theories about this condition, and it seemed very mysterious until the concept of a closed-in expandable space and measuring the pressure within was adopted. The current body of knowledge unequivocally reflects that untreated ACS leads to tissue necrosis, permanent functional impairment, and, if severe, renal failure and death ***[1]***.

In CS, the circulation and function of tissues within a closed space are compromised by increased pressure within the osseofascial compartment as well as an accumulated fluid and/or external compression creates high pressure within a closed fascial space, reducing perfusion of the tissues within the compartment below a level that is necessary for viability ***[2]***. Compartment syndromes may be acute or chronic, based on their cause and reversibility ***[3]***.

An acute compartment syndrome (ACS) is a severe condition that is usually caused by trauma, in which intra-compartmental pressure (ICP) is elevated to a high level for long enough that capillary flow is impeded, and decompression is necessary to prevent necrosis and preserve limb viability ***[4]***. Commonly used terms for ACS are anterior tibia syndrome, calf hypertension, compartmental syndrome, Volkmann's ischemia, and impending ischemic contracture. However, Volkmann's ischemia and impending ischemic contracture should not be used as they do not define the cause of the ischemic problem ***[5]***.

Chronic compartment syndrome (CCS) is mild and recurrent and most commonly associated with exercise, occurs when ICP is raised sufficiently to produce ischemia, pain, and/or neurological deficit ***[1]***. Chronic exertional compartment syndrome (CECS) can affect athletes of any age, especially adolescents. Anyone whose sport involves a lot of running or jumping, or indeed long-distance walking, may be at risk ***[6]***. It usually occurs in the lower limb, where there are four tightly packed muscle compartments, especially the anterior compartment, as it contains the tibialis anterior muscle; however, the thigh and foot are also vulnerable to be affected ***[7]***.

Treatment of CECS in the first instance can be done by changing training regimes, or complete rest may resolve the symptoms, especially if diagnosed at an early stage ***[8]***. The CECS is usually not identified early, and each successive episode of inflammation and irritation will cause the compartment fascia to thicken and become fibrotic, making it increasingly unlikely to be able to return to its normal state of yield even with rest ***[9]***. Although there have been reports of successful conservative treatment, massage and physiotherapy alone are rarely satisfactory, whereas fasciotomy (surgical incision of the fascia) is considered the treatment of choice ***[10]***.

Materials and Methods

A. Patients

This prospective study included 20 patients aged 21-58 years with unilateral closed leg bones fracture that was presented to Shar Hospital, Sulaimaniyah City, Northern Iraq between October 1st, 2018 to July 1st, 2020.

B. Inclusion criteria

Patients with unilateral closed leg bones fracture aged 18 to 60 years old were included in this study.

C. Exclusion criteria

Patients with chronic diseases (such as hypertension, diabetes mellitus, and hypercholesterolemia), compound fractures, multiple life-threatening injuries, traumatic brain injury or unconsciousness, additional fracture of ipsilateral or contralateral extremity, manifested compartment syndrome, and blood coagulation

disorders were excluded from this study. Additionally, those aged <18 or >60 or presented to the hospital >6 hours after injury were also excluded.

D. Clinical intervention

The patients were followed 3 days before the establishment of the definitive treatment and measurement of the ICP. Also, they followed clinically by looking at features of the compartment, which include pain out of proportion to what is expected, paresthesia, and paralysis. Sociodemographic data (age and gender), date and mechanism of injury, severity (low and high energy fractures), side and site of a fractured leg, and fracture's type according to Oestern and Tscherne classification of the fracture were collected from each participant.

At admission to the emergency department, the "ABC" of initial management (A: Airway, B: Breathing, and C: Circulation) was addressed first; followed by primary stabilization of the fracture (elevation of the fractured leg). As well, a thorough clinical examination with blood pressure measurement was performed. Then, the ICP was measured for the fractured leg close to the fracture site (within 5 cm from the fracture site) and recorded as baseline readings for the compartments of the fractured leg. Also, the ICP was measured for the normal leg and recorded as a control. All ICP measurements were done in the anterior compartment using Whiteside's needle-infusion technique.

Depending on the baseline ICP measurement, the patients were classified into 3 regimes. The first regime included normotensive patients that had ICP within the normal limit (ΔP >35 mmHg). These patients were re-examined regularly; looking for one of the features of impending ischemia such as any unusual severe pain in the fractured leg, unusual swelling and tenseness of the affected compartment, presence of numbness or paranesthesia, pain on passive stretching of the muscles of the affected compartment, and paresis or paralysis of muscles of the affected compartment. These regular checkings were done every 3 hours for the first 24 hours, then every 6 hours for the next 24 hours, and then twice daily during the next 24 hours. If the patient had any one of the above features, then the second regime was followed, but when the patient had more than one of the above features, or the ICP increased to a critical limit, then the third regime was followed.

The second regime included normotensive patients with ICP higher than the normal limit (Δp: 30 - 35 mmHg) but with/without only one clinical sign or symptom of impending ischemia. These patients were re-examined regularly every hour, and ICP was measured every 6 hours. If the patient had more than 1 of the above features, or the ICP increased to a critical limit, the third regime was followed. The third regime included normotensive patients with *a* high ICP value (ΔP <30 mmHg). When the patient had more than one feature of the signs and symptoms of impending ACS, all the dressings and plaster casts were opened, the leg was lowered to the level of the heart, re-examined every hour, and ICP was measured hourly.

On the other hand, urgent surgical decompression fasciotomy was assumed to be performed according to the following criteria [(28)]: If the patient had more than one feature of impending ischemia lasting >4 hours, or more features appeared even if the ICP was within the normal limit (ACS diagnosed only by clinical findings) or when the patient had one feature of impending ischemia with high ICP (Δp <30 mmHg) on 2 successive measurements (ACS diagnosed clinically and by ICP measurement).

E. Statistical analysis

The results are expressed as mean ± SD and analyzed statistically using SPSS version 27.0 (SPSS Inc., Chicago, USA). Probability values of less than 0.05 ($p<0.05$) should be considered statistically significant.

F. Ethical approval

The ethical approval to conduct this research was obtained from the Ethical Committee of College of Medicine, University of Sulaimani, and all measures were taken to minimize pain or discomfort to the patients, and procedures were carried out following the ethics guidelines of the College of Medicine, University of Sulaimani.

Results

Among 20 patients (aged 21-58 years), we realized that males (75%) were more affected than females (25%), and the majority of the patients (35%) were aged 36 - 45 years old (Table 1).

Also, we found that 50% of the fractures occurred in the lower third leg, 20% at the upper third, and the rest were in the middle third of the legs. Most of the fractures (85%) were found in the tibia and fibula, while 15% were found only in the tibia. Regarding the side of the fracture, about 60% of the fractures were found in the right leg and the rest found in the left leg. The fracture comminution presented in 45% of the fractures (Table 2).

Table 1. Age and gender distribution of the patients.

Age (Years)	Gender		Total (%)
	Male (No.)	Female (No.)	
16-25	3	2	5 (25 %)
26-35	3	1	4 (20 %)
36-45	6	1	7 (35%)
46-55	2	1	3 (15 %)
56-65	1	0	1 (5 %)
Total (%)	15 (75%)	5 (25 %)	20 (100 %)

Table 2. Site and side of injury, types of the fracture, and parts of bone involved in patients with leg fractures.

Site of the leg fracture	Fracture of tibia alone				Fracture of tibia and fibula				Total
	Comminuted fractures		Non-comminuted fracture		Comminuted fractures		Non-comminuted fractures		
	Left leg	Right leg	Left leg	Right leg	Left leg	Right leg	Left leg	Right leg	
Upper 1/3	0	1	0	0	0	2	1	0	4
Middle 1/3	0	0	0	0	2	1	0	3	6
Lower 1/3	0	0	1	1	2	1	4	1	10
Total	1		2		8		9		20

Regarding the causes of the fracture, we realized that 40% of the fractures were caused by the road traffic accident, 40% by fall from height, and 20% resulted from domestic falls (Table 3).

Table 3. Causes of the leg bone fracture in studied patients.

Causes of the fracture	No. of patient	%
Road traffic accident	8	40
Fall from height	8	40
Domestic fall	4	20
Total	20	100

The ICP and ΔP at the time of admission for all patients were distributed into 2 groups; the first group includes 4 patients (20%) that had ICP of 36-40 (Δp <35 mmHg) at the time of presentation and followed the second regime. At the same time, the second group includes 16 patients (80%) that followed the first regime (Δp >35 mmHg) (Table 4).

The follow-up over 3 days showed that at the time of admission, 80% of the patients followed the first regime, and 20% followed the second regime. After 3 hours, 70% followed the first regime, and 30% followed the second regime. After 12 hours, 65% followed the first regime, 30% followed the second regime, 5% ended with fasciotomy) and after 18 hours, all patients followed the first regime (Table 5).

Table 4. The ICP and ΔP for the fractured and normal leg at admission to the emergency ward with the proposed regime to follow.

Measurement (mmHg)	ICP		The proposed regime to follow	ΔP		The proposed regime to follow
	Fractured leg	Normal leg		Fractured leg	Normal leg	
0-5	0	5	-	0	0	-
6-10	0	12	-	0	0	-
11-15	0	3	-	0	0	-
16-20	3	0	1st	0	0	-
21-25	1	0	1st	0	0	-
26-30	6	0	1st	0	0	-
31-35	6	0	1st	4	0	2nd
36-40	4	0	2nd	4	0	1st
41-45	0	0	-	3	0	1st
46-50	0	0	-	4	0	1st
>50	0	0	-	5	0	1st
Total	20	20		20	0	-

Table 5. Number of patients with their regimes over the three days of the follow-up.

Followed regime	During first 24 hrs									During 24-48 hrs				During 48-72 hrs	
	At the time of	After 3 hrs	After 6 hrs	After 9 hrs	After 12 hrs	After 15 hrs	After 18 hrs	After 21 hrs	After 24 hrs	After 30 hrs	After 36 hrs	After 42 hrs	After 48 hrs	After 60 hrs	After 72 hrs
1st regime	16	14	11	11	13	17	19	19	19	19	19	19	19	19	19
2nd regime	4	6	9	6	6	2	0	0	0	0	0	0	0	0	0
3rd regime	0	0	0	3	1*	0	0	0	0	0	0	0	0	0	0
Total	20	20	20	20	20	19	19	19	19	19	19	19	19	19	19

*The patient underwent fasciotomy

Regarding the case (55 years old) that underwent the fasciotomy, he was presented with segmental fracture after RTA, started with the first regime, and 6 hours later changed to the second regime. After 9 hours, manipulation was done to him, and after 11 hours, his Δp was 25 mmHg, then the third regime was followed. An hour later, ΔP was reached 30 mmHg and decreased to 23 mmHg after 1 more hour (Table 6).

Table 6. Clinical findings and the ΔP for the patient who underwent fasciotomy.

Clinical Finding	**At the time of admission**	**After 3 hrs**	**After 4 hrs**	**After 5 hrs**	**After 6 hrs**	**After 7 hrs**	**After 8 hrs**	**After 9 hrs**	**After 10 hrs**	**After 11 hrs**	**After 12 hrs**	**After 13 hrs**
ΔP (mmHg)	45	-	-	-	38	-	-	33		25	30	23
Unusual swelling and tenseness	-	-	-	-	+	+	+	+	+	+	+	+
Unusual pain	-	-	-	-	-	-	-	-	-	+	+	+
Numbness and paresthesia	-	-	-	-	-	-	-	-	-	-	+	+
Painful passive stretch	-	-	-	-	-	-	-	-	-	-	-	+
Paresis or paralysis	-	-	-	-	-	-	-	-	-	-	-	-
Followed regime	1st	1st	1st	1st	2nd	2nd	2nd	2nd	2nd	3rd	3rd	Fasciotomy

Regarding the Oestern and Tscherne classification in association with the proposed regime, the patients were grouped based on their Δp-value at the time of the presentation. It was revealed that 50% of the patients had type 1 (C1) fracture, 30% had type (C0) fracture, and 20% had type 2 (C2) fracture, of which 80% of them followed the first regime while 20% followed the second regime.

Table 7. Shows correlation between the Oestern and Tscherne classification and followed regime about Δp-value.

Δp (mmHg)	**Oestern and Tscherne classification**			**Followed regime**	**Total**
	C0	**C1**	**C2**		
25-30	-	-	-	-	-
31-35	-	2	2	2nd	4
36–40	1	3		1st	4
41-45		1	2	1st	3
46-50	2	2	-	1st	4
>50	3	2	-	1st	5
Total	6	10	4	-	20

Regarding the mean differential pressure (Δp) concerning the type of the fracture, it was found that there was a significant correlation ($p<0.002$) between the type of the fracture and the level of the differential pressure (Figure 8).

Table 8. Shows differential pressure concerning the type of fracture.

Oestern and Tscherne classification	**Δp (mmHg)**				**P-value**
	At the time of admission	**After 6 hrs**	**After12 hrs**	**After 18 hrs**	
C0 (6 patients)	51	49.66	51.66	57.83	<0.002
C1(10 patients)	42.8	39.66	45.07	51.5	
C2 (4 patients)	39.3	31.25	34.25	46.25	

The severity of the fracture and the followed regime associated with the Δp-value at the time of the presentation is shown in Table 9. About 55% of the patients were presented with low energy fracture and 45% with high energy fracture, in which 4 of the latter were followed the second regime.

Table 9. Shows the severity of the fracture concerning the Δp at the time of presentation.

Δp (mmHg)	**The severity of the fracture**		**Followed regime**	**Total**
	High energy fracture	**Low energy fracture**		
31-35	4		2nd	4
36-40	2	2	1st	4
41-45	2	1	1st	3
46-50	1	3	1st	4
>50	-	5	1st	5
Total	9	11		20

At the time of presentation, 4 patients had ΔP of 31-35 mmHg (upper normal) and followed the second regime while the rest had normal ICP. After 3 hours of admission, 2 patients developed symptoms and followed the second regime. Then, 6 hours later, another 3 patients developed the symptoms of the compartment where also followed the second regime. After 9 hours of admission, 3/9 patients were developed more symptoms of the compartment with decreased Δp to <30 mmHg; therefore, a third regime was followed (the leg put at the level of the heart and any tight structures were removed with close observation to the leg), then ICP decreased with increased Δp.

After 12 hours of admission, 3 patients that followed the third regime were returned to the second regime and 2 patients that followed the second regime changed to the first regime, and 1 patient after 13 hours had established features of the compartment and underwent fasciotomy. After 15 hours, only 2 patients followed the second regime, and 17 patients followed the first regime. After 18 hours, 19 patients followed the first regime (Table 10).

Table 10. Shows the relationship between the change in the ICP and the appearance of the clinical features.

Items	**Follow up of the patients**				**P-value**
	At the time of admission	**After 6 hrs**	**After 12 hrs**	**After 18 hrs**	<0.05
Δp (mmHg)	44.36	40.19	43.66	51.94	
No. of clinical features appeared over the time	4	10	8	0	

Discussion

ACS is a serious surgical emergency in which its early diagnosis and treatment are of significant importance to avoid long-term disability and is commonly associated with a close fracture of the leg ***[11]***.

In this study, most of the patients (55%) were aged 26 to 45 years which is similar to a study by Saikia et al., 2008 where they reported that 65% of patients aged in this range and are probably due to that this age is the age of the hard duties and outdoor works ***[12]***. Regarding gender concern, males were mainly affected (75%) than females as they are more involved in heavy outdoor jobs, similar to a study done by Yadav et al., 2015 ***[13]***. Accordingly, Erdös et al., 2011 found that most patients with fractured tibia were males in their middle-age life ***[14]***.

In this current research, the lower third of the tibia was the most familiar part of fracture (50%), which explained the high incidence of using the first regime (the less muscle content and bones are less cancellous). Whereas, the increased ICP reported more with the fracture of the upper third associated with increased incidence of ACS, and patients had considerable bleeding and swelling of their legs ***[15]***. On the other hand, the fractures were comminuted in 9 patients (45%) that might be since the causes of the fractures were high energy injuries (road traffic accidents and fall from height), and severe injury is considered as one of the risk factors of increasing the ICP ***[16]***.

We measured the ICP of the anterior compartment, which is the most commonly involved compartment of the leg in ACS. In this respect, McQueen et al. ***[17]***, Gershuni et al. ***[18]***, and Sheridan et al. ***[19]*** also reported constant involvement of the anterior compartment in tibial fracture complicated by ACS.

Moreover, we considered the $\Delta p < 30$ mmHg between diastolic and compartment pressure to be critical and an indication for decompression. The essential level of absolute tissue pressure above which decompression should be performed has always been variably reported. Generally, the ischemia begins when Δp rises to 10–30 mmHg of diastolic pressure ***[20]***; however, according to McQueen et al.;, absolute compartmental pressure is an unreliable indication of fasciotomy ***[17]***.

Furthermore, we measured the ICP within 5 cm from the fracture site as the differences in pressures over a distance of around 5 cm were significant in making the diagnosis. Heckman et al. showed that there was a relationship between ICP and distance from the actual fracture site in cases of closed tibia fractures. The highest pressures were routinely found at or within 5 cm of the fracture site ***[21]***.

Regarding the fasciotomy case that was presented with a close fracture of both tibia and fibula (type 2 fracture) after RTA; the first regime was followed at the time of presentation; then, after 6 hours, his pain increased, and the second regime was followed, and after 4 hours, he developed a severe pain with unusual swelling with decreased Δp to <30 mmHg; therefore, the third regime was followed, finally, after 13 hours, he underwent fasciotomy. In this case, we depended on the clinical features and the measurement of the ICP to diagnose compartment syndrome, and we found a significant association between them ($p<0.05$).

Additionally, we found a significant ($p<0.002$) correlation between high energy injury and lower differential pressure using ICP measurements to confirm the clinical diagnosis of ACS. Thus, in our study, ACS was diagnosed in only 1 patient (5%) (55-years old male due to the traumatic injuries) after manipulation and application of the slab. In this concern, a study showed that manipulation is the main factor that predisposes to increase ICP and leads to ACS ***[22]***. Therefore, it is important not to neglect any case of close fracture of the tibia after primary immobilization by back slab and especially comminuted fracture because manipulation of the fracture is an important factor that leads to the development of the missed compartment ***[23]***.

Conclusions

We concluded that there is a significant correlation between the measurement of ICP and the clinical signs of impending CS in early recognition and diagnosis of ACS after closed leg bone fractures. Also, we found that the close observation of the patient for features of ischemia (pain out of the proportion, tense compartment, pain on passive stretching of the toes, paresthesia, and paralysis) is enough to diagnose the threatened leg by compartment. A high index of suspicion, early diagnosis, and immediate treatment are essential in the avoidance of missing ACS and its sequels. Unusual swelling and tenseness alone should not be the sole indicator for decompression. Finally, we realized that fracture grade has the strongest influence on the measurement of differential pressure, where high energy fracture is associated more with the compartment syndrome.

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