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Absolute compartment pressure versus differential pressure for the diagnosis of compartment syndrome in tibial fractures

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Abstract We studied 39 patients with 42 diaphyseal tibial fractures in whom we suspected a high risk for the development of a compartment syndrome. We measured the anterior absolute compartment pressure (ACP) every 12 h for 72 h and also recorded the differential pressure (ΔP =diastolic blood pressure–ACP). Fasciotomy of the extremity was only performed when the differential pressure was less than 30 mmHg for more than 30 min. The highest values of the ACP were recorded between 24 h and 36 h after admission. Three fractures had a differential pressure less than 30 mmHg and all were treated by fasciotomy. In three fractures the ACP was equal to or higher than 50 mmHg, of which two had a differential pressure less than 30 mmHg. The patients were followed up for a mean of 36 months (29–45). All fractures healed, and none of our patients showed any sequelae of compartment syndrome at their last review.

Résumé Nous avons étudié 39 malades avec 42 fractures tibiales diaphysaires que nous avons suspecté d'un syndrome compartimental. Nous avons mesuré la pression du compartiment antérieure (ACP) chaque 12 h pendant 72 h et avons aussi enregistré la pression différentielle (ΔP =tension diastolique–ACP). Une fasciotomie de la jambe a été exécutée seulement quand la pression différentielle était inférieure à 30 mmHg pendant plus de 30 min. Les plus hautes valeurs de l'ACP ont été enregistrées entre 24 et 36 h après l'admission. Trois fractures avaient une pression différentielle de moins de 30 mmHg et toutes ont été traitées par fasciotomie. Dans trois fractures l'ACP était égale ou supérieure à 50 mmHg, avec, pour deux, une

pression différentielle de moins de 30 mmHg. Les malades ont été suivis pendant une moyenne de 36 mois (29–45). Toutes les fractures ont guéri et aucun de nos malades n'a montré de séquelle d'un syndrome de compartiment à la dernière révision.

Introduction

Acute compartment syndrome (ACS) is the most important complication of tibial diaphyseal fractures [2, 4, 11, 13]. Early diagnosis and treatment with decompression is the goal of the surgeon in order to avoid devastating consequences [5].

Although the clinical findings and recently reported spectroscopic methods can be used in the diagnosis of tissue ischaemia, compartment pressure monitoring is still advocated by many authors as the principal criterion for early diagnosis of ACS [1, 12, 16, 23]. There is still a heated debate regarding the critical level of the absolute compartment pressure (ACP) threshold. Various authors report different values. Hargens et al. [6] and Mubarak et al. [14, 15] accepted an ACP of 30 mmHg as the critical pressure for occlusion of the intracompartmental microvasculature, as this corresponds with normal capillary pressure. On the other hand, Matsen et al. [10] accepted 45 mmHg as the threshold for decompression.

The importance of the differential pressure (ΔP =Diastolic blood pressure–ACP) levels was first reported by Whiteside et al. [16, 22], who stated that ischemia begins when pressure rises to within 10–30 mmHg of the diastolic blood pressure. McQueen et al. also reported that using a differential pressure of 30 mmHg as a threshold for fasciotomy led to no missed cases of ACS [12].

Materials and methods

This prospective study was conducted at Ege University Hospital, Izmir, Turkey and was approved by the institutional scientific board. Between October 1999 and

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March 2001, 71 patients with 76 tibial diaphyseal fractures were treated in the department of Orthopaedics and Traumatology. Of these fractures, 52 were closed and 24 were open; 50 were due to high-energy trauma and 26 to low-energy trauma.

We designed a prospective study of patients with tibial diaphyseal fractures and a clinical suspicion of possible ACS. The clinical suspicion was defined as diffuse pain and swelling, which was not relieved by immobilisation, whether or not associated with pallor or paraesthesia. Patients with additional injuries necessitating an urgent operation or open wounds which made monitoring impossible, or admission to hospital later than 3 h after injury were excluded. Other exclusions were patients less than 12 years of age, patients who refused insertion of a catheter, and patients with coagulation disorders, peripheral neuropathy or previous fracture of the same extremity.

There were 26 male and 13 female patients with an average age of 34 (13 to 75) years having 42 tibial diaphyseal fractures who met the inclusion criteria.

The majority had been involved in traffic accidents and 37 patients had been injured in a high-energy trauma. Twenty-six patients were polytraumatised. Nine had an additional head injury, 18 had an additional long bone fracture, 17 had a chest and seven had abdominal trauma. The patient data are summarised in Table 1.

Compartment pressure monitoring

Compartment pressure monitoring started at an average of 2 h (1–3) after the injury using a pressure-monitoring device (Stryker Surgical, Kalamazoo, Michigan, USA). A slit catheter was introduced into the desired compartment under local anaesthesia. The compartment pressures of all four compartments of the lower leg were measured initially in all patients. In all cases the initial ACP was found to be the higher in the anterior compartment than in the other compartments and continuous monitoring was therefore carried out only in this compartment. The anterior compartment was monitored continuously for 72 h and pressures were recorded every 30 min together with the simultaneous blood pressure values. The mean ACP and ΔP values of the six 12-h intervals were calculated. When ΔP was found to be <30 mmHg in one recording, fasciotomy was considered only if ΔP continued to be <30 mmHg in a second recording made after 30 min. In 11 cases suspected to be at high risk of developing ACS, monitoring was continued until the fifth day after admission.

Treatment and follow-up

In 15 cases a posterior plaster splint and in 27 cases calcaneal traction was used prior to definitive treatment. As we thought that fracture treatment might increase the ACP, definitive treatment was delayed until no earlier than 72 h after the injury. As shown in Table 1 the patients were

treated by conservative or surgical methods using different techniques of internal and external fixation. Patients were followed up clinically every 2nd week and radiographically every 4th week. The mean follow-up period was 36 months (29–45).

Statistical analysis

The difference between mean ACP and ΔP values of the periods were first tested using repeated-measurement analysis of variance (ANOVA), and after the differences between all periods were found to be statistically significant, the paired *t*-test was further used to analyse the individual differences between paired periods with regard to mean ACP. The relationship between ACP and ΔP values of each period was tested using Pearson moment product correlation coefficient analysis.

The difference between the ACP values in the two groups of patients treated by posterior splint or calcaneal traction was tested using repeated-measurement ANOVA. The relationship regarding ACS development was analysed using Fisher's exact test. The difference between the open and closed fractures with respect to ACP and ΔP was tested using Student's *t*-test.

The relationship between ACP and fracture healing time was analysed using simple linear regression analysis. The effect of the location of the fracture on the ACP was tested by one-way ANOVA. In all statistical analyses significance level (α) was taken as 0.05 and the power of these tests ($1-\beta$) was calculated using this α value.

Results

All patients except one, who died from cranial trauma, were available for follow-up.

The average ACP was 29.9 mmHg in the overall 72-h period (Table 2). The highest ACP values were recorded in the third period. The difference between the mean ACP values in the various periods was statistically significant ($p<0.0001$). The average ΔP was 48.98 mmHg in the overall 72-h period. The lowest ΔP values were recorded in the third period. The difference between the mean ΔP values in the various periods was also statistically significant. In fractures initially treated with calcaneal traction the mean ACP was 31.41 (± 8.74) mmHg, while in fractures treated with a posterior splint the mean ACP was 27.26 (± 6.29) mmHg. Whether the fracture was open or closed was of no significance for the measured values. Neither was it of any significance whether the fracture was initially treated with a posterior splint or with calcaneal traction.

ACP was found to be equal to or higher than 30 mmHg in 33 cases at any time in the overall 72-h period but only three cases had ΔP equal to or less than 30 mmHg. These three fractures were treated with fasciotomy. Two were from the calcaneal traction group and one from the group treated initially with a posterior splint.

Table 1 Descriptive data of the patients

Case	Sex and age (years)	Side	Aetiology	Trauma energy	Polytrauma	Gustilo classification (for open fractures)	Tscherne classification (for closed fractures)	Treatment method	Fasciotomy
1	♀, 48	Left	Traffic accident	High	+		Fr.C.I	ORIF	—
2	♂, 22	Right	Traffic accident	High	—		Fr.C.0	ORIF	—
3	♂, 27	Bilateral	Traffic accident	High	+	IIIC	Fr.C.II	Conservative	—
								Ilizarov technique	—
4	♂, 50	Right	Traffic accident	High	+	II		Ilizarov technique	—
5	♂, 35	Left	Traffic accident	High	—	IIIB		IM fixation	—
6	♀, 45	Left	Traffic accident	High	—		Fr.C.0	IM fixation	—
7	♀, 19	Right	Fall	High	+		Fr.C.I	ORIF	—
8	♀, 45	Right	Fall	Low	—		Fr.C.0	IM fixation	—
9*	♂, 47	Left	Traffic accident	High	—		Fr.C.0	ORIF	+
10	♂, 20	Right	Gunshot	High	—	IIIB		IM fixation	—
11*	♂, 17	Left	Traffic accident	High	+		Fr.C.I	IM fixation	+
12	♀, 69	Left	Traffic accident	High	+		Fr.C.II	ORIF	—
13	♀, 13	Right	Traffic accident	High	—		Fr.C.I	Conservative	—
14	♀, 44	Right	Traffic accident	High	—		Fr.C.I	IM fixation	—
15	♀, 44	Right	Traffic accident	High	+		Fr.C.I	IM fixation	—
16	♂, 40	Left	Traffic accident	High	+		Fr.C.II	Ilizarov technique	—
17	♂, 19	Right	Traffic accident	High	—		Fr.C.I	IM fixation	—
18	♂, 27	Right	Traffic accident	High	+		Fr.C.I	IM fixation	—
19*	♂, 46	Left	Traffic accident	High	+	IIIA		IM fixation	+
20	♀, 75	Left	Traffic accident	High	+		Fr.C.I	IM fixation	—
21	♂, 20	Right	Traffic accident	High	+	I		IM fixation	—
22	♂, 22	Left	Traffic accident	High	+		Fr.C.I	Conservative	—
23	♂, 37	Right	Gunshot	High	—	IIIB		Ilizarov technique	—
24	♂, 39	Right	Traffic accident	High	+		Fr.C.I	IM fixation	—
25	♂, 18	Left	Fall	Low	—		Fr.C.I	Conservative	—
26	♂, 20	Right	Traffic accident	High	—	II		IM fixation	—
27	♂, 15	Left	Traffic accident	High	+		Fr.C.I	IM fixation	—

Table 1 (continued)

Case	Sex and age (years)	Side	Aetiology	Trauma energy	Polytrauma	Gustilo classification (for open fractures)	Tscherne classification (for closed fractures)	Treatment method	Fasciotomy
28	♂, 19	Left	Traffic accident	High	+	IIIB		IM fixation	–
29	♂, 42	Left	Traffic accident	High	–	IIIC		Ilizarov technique	–
30	♂, 19	Right	Traffic accident	High	+		Fr.C.I	IM fixation	–
31	♂, 54	Bilateral	Traffic accident	High	+		Fr.C.I	IM fixation	–
							Fr.C.II	Ilizarov technique	–
32	♀, 21	Left	Traffic accident	High	+		Fr.C.I	External Fixation	–
33	♂, 38	Left	Fall	High	+		Fr.C.II	External Fixation	–
34	♂, 20	Left	Traffic accident	High	+	II		Conservative	–
35	♂, 57	Left	Traffic accident	High	+		Fr.C.II	IM fixation	–
36	♂, 27	Left	Traffic accident	High	+	II		Conservative	–
37	♀, 36	Left	Traffic accident	High	+	II		Conservative	–
38	♂, 38	Bilateral	Traffic accident	High	+		Fr.C.0	IM fixation	–
							Fr.C.I	IM fixation	–
39	♀, 40	Right	Traffic accident	High	+		Fr.C.I	Ilizarov technique	–

*Patients who were diagnosed to have ACS and had fasciotomy

When the third period, in which the highest compartment pressures were recorded was considered, the mean ACP was found to be 30–39 mmHg in 13 cases, 40–49 mmHg in 12 cases and over 50 mmHg in three cases of which two had ΔP less than 30 mmHg. At the end of the follow-up period no complications related to a possible ACS was observed in any of the remaining patients.

All fractures united and there were no cases of deep infection, curly toes or other foot problems at the last visit.

The muscle strengths of the lower leg and foot were assessed clinically and there was no specific loss of strength or function except in two patients with type IIIC open fractures associated with peroneal nerve palsy. The mean fracture union time was 4.5 months (2–7) in 28 cases with a mean ACP higher than 30 mmHg, and 5.9 months (3–10) in 13 cases with a mean ACP lower than 30 mmHg in the third period.

Table 2 The minimum, maximum and mean ACP and ΔP values recorded in the various periods

Period	Mean ACP, mmHg ($\pm$ SD)	Min. and max. ACP (mmHg)	Mean ΔP , mmHg ($\pm$ SD)	Min. and max. ΔP (mmHg)
1	30.40 ($\pm$ 8.08)	17.00–50.00	47.69 ($\pm$ 8.47)	25.00–63.00
2	33.09 ($\pm$ 7.85)	20.00–50.00	45.47 ($\pm$ 8.30)	30.00–62.00
3	34.54 ($\pm$ 8.07)	22.00–53.00	45.21 ($\pm$ 7.77)	27.00–59.00
4	31.81 ($\pm$ 9.57)	18.00–54.00	47.23 ($\pm$ 9.12)	26.00–62.00
5	27.33 ($\pm$ 9.82)	15.00–55.00	51.59 ($\pm$ 9.80)	24.00–65.00
6	22.35 ($\pm$ 10.43)	12.00–54.00	56.69 ($\pm$ 10.19)	26.00–68.00
Total time of 72 h	29.92 ($\pm$ 8.12)	20.50–51.33	48.98 ($\pm$ 7.98)	27.83–59.50

Discussion

The primary treatment of ACS is decompression of the compartment by fasciotomy. As fasciotomy can lead to serious complications unnecessary fasciotomies should be avoided, especially in polytraumatised patients [4, 5, 11].

There are numerous methods used in the early diagnosis of compartment syndrome. The diagnosis can be easily established in the conscious patient, but could be missed in a polytraumatised patient as physical examination has poor sensitivity and specificity [1, 11, 23]. Current concepts favour two methods for the diagnosis of compartment syndrome. The first concept uses ACP values higher than 30–40 mmHg and the second uses ΔP lower than 30 mmHg as an indication for fasciotomy [14, 15, 18]. The second concept relies on Whiteside's theory, which states that blood pressure can decrease or increase the effect of ACP on the tissue perfusion [9, 11, 12].

This study investigated the effectiveness of ΔP in the early diagnosis of compartment syndrome. The primary finding of this study was that ΔP was superior to ACP in the early diagnosis of ACS. If ACP higher than 30 mmHg had been accepted as the sole criterion in the diagnosis of ACS, 33 fasciotomies would have been done whereas only three were done in patients who had ΔP below 30 mmHg. This avoided 30 unnecessary fasciotomies. In the third period, even if the ACP limit had been increased to 50 mmHg three fasciotomies would have been performed; however, only two of them were necessary.

DeLee and Stiehl [2] reported that the risk of ACS was the same in open fractures as in closed fractures. This is supported by our findings in the present study. Shakespeare and Henderson [19] reported that traction caused an additional increase in the ACP in tibial fractures. We found a higher mean ACP value in the group of fractures treated with skeletal traction, but there was no statistically significant difference from the group of fractures treated with a posterior splint.

There are conflicting reports on the effect of acute reamed intramedullary nailing on ACP. Tornetta and French [21] reported that it is safe without traction, but Tischenko and Goodman [20] reported that procedures like intramedullary nailing, which involve forceful traction for a long time, may predispose to ACS. Kutty et al. [8] showed that traction as an aid unnecessarily increases compartment pressures. In view of these findings we delayed the fracture treatment to the end of the monitoring period as we thought that definitive treatment might interfere with the results.

In this study a gradual increase in the mean ACP values was observed until the third period, in which the highest values were recorded. In contrast, ΔP values showed a gradual decrease until the third period, in which the lowest values were recorded. In the later periods these values increased again to return to their previous first period levels. In the light of these findings, we believe that the most critical time for the early diagnosis of ACS is the

period 24–36 hours after the initial injury and ACP monitoring should be continued until the end of this period.

Although compartment syndrome is usually diagnosed as an acute entity, missed cases with subtle symptoms can also be diagnosed later with the help of clinical symptoms such as loss of muscle strength [1, 7]. Early [3] reported that 2% of tibial fractures were complicated with loss of function of the feet. In this study, all of the patients were examined clinically to reveal any possible motor or nerve dysfunction or sequelae of a missed compartment syndrome. No such findings were observed at the end of the follow-up period. Neither did we observe any complications such as infection or non-union. One drawback of this study is the lack of quantitative muscle strength measurements and podometric studies as proposed by Ovre et al. [17].

References

1. Bourne RB, Rorabeck CH (1989) Compartment syndromes of the lower leg. *Clin Orthop* 240:97–104
2. DeLee JC, Stiehl JB (1981) Open tibia fracture with compartment syndrome. *Clin Orthop* 160:175–184
3. Early JS (1996) Anterior compartment syndrome and the treatment of its sequelae. *Orthopaedics* 4:197–203
4. Gershuni DH, Mubarak SJ, Yaru NC, Lee YF (1987) Fracture of the tibia complicated by acute compartment syndrome. *Clin Orthop* 217:221–227
5. Gulli B, Templeman D (1994) Compartment syndrome of the lower extremity. *Orthop Clin North Am* 25:677–683
6. Hargens AR, Akeson WH, Mubarak SJ (1978) Fluid balance within the canine anterolateral compartment and its relationship to compartment syndrome. *J Bone Joint Surg Am* 60:499–505
7. Karlstrom G, Lonnerholm T, Olerud S (1975) Cavus deformity of the foot after fracture of the tibia shaft. *J Bone Joint Surg Am* 57:893–900
8. Kutty S, Laing AJ, Prasad CV, McCabe JP (2005) The effect of traction on compartment pressures during intramedullary nailing of tibial-shaft fractures. A prospective randomised trial. *Int Orthop* Apr 7; [Epub ahead of print]
9. Matava MJ, Whitesides TE, Seiler JG, Hewan-Lowe K, Hutton WC (1994) Determination of the compartment pressure threshold of muscle ischemia in a canine model. *J Trauma* 37:50–58
10. Matsen FA, Winquist RA, Krugmire RB (1980) Diagnosis and management of compartmental syndromes. *J Bone Joint Surg Am* 62:286–291
11. McQueen MM, Christie J, Court-Brown CM (1996) Acute compartment syndrome in tibial diaphyseal fractures. *J Bone Joint Surg Br* 78:95–98
12. McQueen MM, Court-Brown CM (1996) Compartment monitoring in tibial fractures: the pressure threshold for decompression. *J Bone Joint Surg Br* 78:99–104
13. McQueen MM, Gaston P, Court-Brown CM (2000) Acute compartment syndrome. Who is at risk? *J Bone Joint Surg Br* 82:200–203
14. Mubarak SJ, Hargens AR, Owen CA (1976) The wick catheter technique for measurement of intramuscular pressure. A new research and clinical tool. *J Bone Joint Surg Am* 58:1016–1021
15. Mubarak SJ, Owen CA, Hargens AR, Garetto LP, Akeson WH (1978) Acute compartment syndromes: diagnosis and treatment with the aid of the wick catheter. *J Bone Joint Surg Am* 60:1091–1095
16. Ogunlusi JD, Oginni LM, Ikem IC (2005) Compartmental pressure in adults with tibial fracture. *Int Orthop* 29(2):130–133

17. Ovre S, Hvaal K, Holm I, Stromsoe K, Nordsletten L, Skjeldal S (1998) Compartment pressure in nailed tibial fractures. *Arch Orthop Trauma Surg* 118:29–31
18. Seiler JG, Casey PJ, Binford SH (2000) Compartment syndromes of the upper extremity. *J South Orthop Assoc* 9:233–247
19. Shakespeare DT, Henderson NJ (1982) Compartmental pressure changes during calcaneal traction in tibial fractures. *J Bone Joint Surg Br* 64:498–499
20. Tischenko GJ, Goodman SB (1990) Compartment syndrome after intramedullary nailing of tibia. *J Bone Joint Surg Am* 72:41–44
21. Tornetta P, French BG (1997) Compartment pressures during nonreamed tibial nailing without traction. *J Orthop Trauma* 11:24–27
22. Whitesides TE, Haney TC, Morimoto K, Harada H (1975) Tissue pressure measurement as a determinant for the need of fasciotomy. *Clin Orthop* 113:43–51
23. Whitesides TE, Heckman MM (1996) Acute compartment syndrome: update on diagnosis and treatment. *J Am Acad Orthop Surg* 4:209–218