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REVIEW ARTICLE

Foot compartment syndrome : A systematic review of the literature

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We systematically reviewed published evidence regarding foot compartment syndrome with regards to causes, methods of diagnosis, number of incisions used for fasciotomy, wound closure techniques, complications, and functional outcomes. Publications were collected using PubMed and OVID databases, and were reviewed as above. All were retrospective case series (evidence-based medicine level IV). Four articles with 39 cases of foot compartment syndrome were reviewed in all. The most common cause of foot compartment syndrome was crush injury to the foot. Diagnosis was mostly made through a combination of clinical findings and compartment pressure measurements. Sixty-five percent of cases required split-thickness skin grafts for wound closure after fasciotomy. Neurological deficits were the most common complication (52%). Thirty-nine percent of the patients reported residual pain and stiffness while ten percent could return to work or their pre-injury activity state after fasciotomy.

Keywords : foot ; compartment syndrome.

INTRODUCTION

Compartment syndrome in the foot occurs when there is an elevation in compartment pressure in any of the nine osseofascial compartments of the foot (*12*), leading to muscle and nerve ischaemia. The sequelae of inadequately managed foot compartment syndrome are poorly tolerated and often necessitate multiple procedures for rehabilitation, ranging from physical therapy with corrective bracing to limb amputation (*3,22*).

To our knowledge, there is limited evidence on the causes of foot compartment syndrome, modalities for treatment, complications, and functional outcome after surgery. The purpose of this paper was to review the available evidence of foot compartment syndrome with regard to causes, methods of diagnosis, number of skin incisions, complications, and functional outcomes.

MATERIALS AND METHODS

This was an institutional review board-exempt study performed at a level-one trauma center. A PubMed search was conducted with the title query : foot, compartment syndrome. This search was without limits, and yielded 284 articles. Another search of the OVID Medical database was performed with the medical subject headings and keywords : foot, compartment, syndrome. This

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yielded 58 articles. One reviewer selected potentially high-yield abstracts, and the full articles were obtained.

Original articles in the English literature discussing compartment syndromes of the foot due to trauma were selected for review. Selected articles were analyzed for cause and mechanism of injury leading to foot compartment syndrome, method of diagnosis, number of skin incisions and techniques at fasciotomy, type of closure performed, complications, and functional outcomes after fasciotomy. Studies focused on chronic or exertional foot compartment syndrome were excluded. Relevant information concerning mean age of patients, gender, average months of follow-up, presence of fractures, type of injury, methods of diagnosis, surgical approaches at fasciotomy, technique at closure, and functional results were carefully extracted.

RESULTS

Four manuscripts were relevant to our research objectives meeting the inclusion criteria (*4,11,20,34*). There were 35 patients with 39 cases of foot compartment syndrome. Four patients had bilateral foot compartment syndrome. There were twenty-seven males and eight females. From the 30 patients with compartment syndrome whose age was specified (*4,11,20*), the average patient age was 32 years (range, 10-58 years). Five patients with foot compartment syndrome were said to be in their twenties (*34*). Average follow-up period was 21 months (range, 3-60 months).

Causes of foot compartment syndrome

Thirty-nine cases were evaluated for the events leading to the development of foot compartment syndrome (table I). Eleven cases were due to crush injuries to the foot. Motor vehicle accidents were responsible for ten cases, motorcycle accidents for three cases, bicycle accident for one case, and train accident for another two cases. Ten cases of foot compartment syndrome were due to falling from a height. There was one recorded case for a gunshot injury and one case for a wrestling injury. In a study of the prevalence of patterns of foot injuries following motorcycle accidents, Jeffers *et al* (*6*) reported three cases of foot compartment syndrome out of 49 motorcyclists with foot injuries.

The distribution of bony injuries causing foot compartment syndrome included nine calcaneal fractures, seven multiple metatarsal and phalangeal fractures, eight Lisfranc type fractures, one peritalar fracture dislocation, and one mid-tarsal fracture (table II). Two cases of foot compartment syndrome were noted for combined Lisfranc and metatarsophalangeal fractures, one case for combined Lisfranc and mid-tarsal fractures, and one case for combined Lisfranc, metatarsophalangeal and mid-tarsal fractures. Two cases were positive only for soft tissue injuries of the foot (*34*). Seven cases of foot compartment syndrome occurred with fractures of ipsilateral leg and upper leg bones without foot fractures (*4,11*).

Table I. — Causes of foot compartment syndrome

Authors	Crush Injury	FFH	MVA	Motorcycle Accident	Bicycle Accident	Train Accident	Gunshot	Wrestling
Ziv *et al* (*34*)	1	–	4	–	–	–	–	–
Myerson *et al* (*20*)	6	2	–	3	1	2	–	–
Fakhouri *et al* (*4*)	3	6	3	–	–	–	–	–
Manoli *et al* (*11*)	1	2	3	–	–	–	1	1
TOTAL	11 (28%)	10 (26%)	10 (26%)	3 (7.5%)	1 (2.5%)	2 (5%)	1 (2.5%)	1 (2.5%)

FFH = Falls from height
MVA = Motor vehicle accident.

Table II. — Distribution of bony injuries to the foot

Bony Injury	Ziv *et al* (*34*)	Myerson *et al* (*20*)	Fakhouri *et al* (*4*)	Manoli *et al* (*11*)	TOTAL
Calcaneal fracture	–	3	5	1	9 (23%)
Subtalar fracture dislocation	–	–	–	1	1 (2.5%)
Mid-tarsal fracture	–	1	–	–	1 (2.5%)
Lisfranc fracture	2	4	2	–	8 (21%)
Metatarsal/phalangeal fracture	1	2	3	1	7 (18%)
Lisfranc, metatarsal/phalangeal fracture	–	2	–	–	2 (5%)
Lisfranc, mid-tarsal fracture	–	1	–	–	1 (2.5%)
Lisfranc, mid-tarsal, metatarsal/phalangeal fracture	–	1	–	–	1 (2.5%)
Leg and upper leg fractures with no foot fractures	–	–	2	5	7 (18%)
Foot soft tissue injuries only	2	–	–	–	2 (5%)

Different configurations of concurrent compartment syndromes of the foot and leg occurred in eleven instances (*4,11*). There were eleven open injuries to the foot, nine of which involved foot fractures (*4,11,20,34*). Concomitant injuries to the chest, head, abdomen, and other limbs were present in nine patients (*4,11*). Baumhauer *et al* (*2*) state that 10-17% of patients with severely traumatized limbs have associated life-threatening injuries. Two patients were described as unconscious with severe head injuries at presentation.

Methods of diagnosis

Twenty-one patients (25 cases) were diagnosed with foot compartment syndrome based on tissue pressure measurements (*4,11,34*) (table III). In two patients with open injuries, foot compartment syndrome was clinically diagnosed on debridement of avulsed tissue exposing the swollen compartment (*34*). Ten patients (12 cases) had a diagnosis made from a combination of clinical findings and compartment pressure measurements (*20*).

Number of skin incisions

Thirteen fasciotomies were performed using a single medial incision only (table IV). Two-incision fasciotomies were done in fifteen cases (*11,20,34*) while nine fasciotomies were done using three (one medial and two dorsal) incisions (*4,11*). Two cases required a fasciotomy through four incisions (one medial, one lateral, and two dorsal) (*4*). Simultaneous calcaneal fracture fixation was performed in two cases (*4*).

Various techniques have been developed to release foot compartment pressures including dorsal, plantar, medial, and lateral approaches (*9,10,19, 28,34*). However, the choice of approach may depend on surgeon's preference, soft tissue injuries, and other planned procedures (*5*).

Table III. — Methods of diagnosis of foot compartment syndrome

Author	Compartment pressure measurement	Clinical findings and compartment pressure measurements	Clinical findings alone
Ziv *et al* (*34*)	3	–	2
Myerson *et al* (*20*)	14	–	–
Fakhouri *et al* (*4*)	–	12	–
Manoli *et al* (*11*)	8	–	–
TOTAL	25 (64%)	12 (31%)	2 (5%)

Table IV. — Number of skin incisions used for fasciotomy

Author	One Incision	Two Incisions	Three Incisions	Four Incisions
Ziv *et al* (*34*)	–	5	–	–
Myerson *et al* (*20*)	5	9	–	–
Fakhouri *et al* (*4*)	6	–	4	2
Manoli *et al* (*11*)	2	1	5	–
TOTAL	13 (33%)	15 (39%)	9 (23%)	2 (5%)

Techniques for wound closure

The type of closure performed for fasciotomy wounds was recorded in 31 cases (*4,11,20,34*). Eight patients had primary split-thickness skin excision with initial temporary skin and muscle flaps (*20,34*). A split-thickness skin graft was performed in twenty cases (*4,20,34*) while eleven cases were closed by delayed primary closure (*4,20*) (table V).

Table V. — Techniques of closure following fasciotomy

Author	Delayed Primary Closure	Split–Thickness Skin Graft
Ziv *et al* (*34*)	–	5
Myerson *et al* (*20*)	3	11
Fakhouri *et al* (*4*)	8	4
Manoli *et al* (*11*)	–	–
TOTAL	11 (35%)	20 (65%)

Complications

Among the 39 cases of foot compartment syndrome in our study, there were 17 recorded complications (44%) (*4,11,20,34*). Varying degrees of neurological deficits were noted in nine cases (table VI). Two patients had clawfoot deformity, two required limb amputation, and another two had significant muscle scarring. There was one case noted for hindfoot valgus deformity and one case for muscle necrosis. Another 15 cases were noted for pain and stiffness symptoms (*4,20*) after foot fasciotomy.

Functional outcome

There were twenty-six recorded cases of outcomes after foot fasciotomy. We evaluated functional outcomes in terms of ability to walk or wear shoes, ability to walk/wear shoes with mild discomfort or symptoms, need for ankle arthrodesis, ability to return to work or pre-injury activity state. Four patients were noted to return to work following fasciotomy (table VII). Five patients were only

Table VI. — Complications reported following compartment syndrome in the foot

Author	Neurological Deficits	Muscle Necrosis	Clawfoot	Amputation	Marked Scarring	Valgus/Varus Deformity
Ziv *et al* (*34*)	2	–	–	–	–	–
Myerson *et al* (*20*)	2	–	1	1	2	1
Fakhouri *et al* (*4*)	2	1	1	1	–	–
Manoli *et al* (*11*)	3	–	–	–	–	–
TOTAL	9 (52%)	1 (6%)	2 (12%)	2 (12%)	2 (12%)	1 (6%)

Table VII. — Postoperative outcomes following fasciotomy for foot compartment syndrome

Author	Return to work	Walk or wear shoes	Walk or wear shoes with mild symptoms or limitations	Require arthrodesis	NA
Ziv *et al* (*34*)	–	5	–	–	–
Myerson *et al* (*20*)	4	–	7	1	2
Fakhouri *et al* (*4*)	–	–	8	–	4
Manoli *et al* (*11*)	–	–	–	1	7
TOTAL	4 (10%)	5 (13%)	15 (39%)	2 (5%)	13 (33%)

described as being able to walk, while fifteen patients could walk, stand, or wear shoes with mild symptoms. Two patients developed post-traumatic arthritis and required ankle fusion due to the traumatic bony injury. Fakhouri *et al* (*4*) also described a post-fasciotomy toe strength of 4.5 of 5 in all their patients.

DISCUSSION

There is limited evidence to guide treatment of foot compartment syndrome. The result of an untreated compartment syndrome in the foot is often myo-neural ischaemic necrosis leading to permanent functional loss associated with contractures, weakness, sensory neuropathy, and ultimately a claw-like deformity (*30*). The goal of treatment in foot injury is, therefore, to maximize function (*17*).

Pain out of proportion to the extent of injury and swelling of the traumatized foot increases the suspicion of foot compartment syndrome. The severe, relentless, burning pain in foot compartment syndrome involving bony injuries to the foot could be related to the large cancellous bone surfaces and the limited osseo-fascial compartment into which the haematoma can dissipate (*17*). Clinically, pain with passive stretch appears to be nonspecific for compartment syndrome. Serial sensory system examinations are often more sensitive than a single sensory examination in the diagnosis of foot compartment syndrome (*5,18*).

The calcaneal compartment may be subject to relatively higher compartment pressures than the other foot compartments while the interosseous compartments have been reported to have the lowest pressures (*10,17,20,25*). Multi-stick catheterization of the various osseofascial compartments of the foot can provide a definitive diagnosis. However, data on baseline normal elevations of compartment pressures after fracture or isolated lower extremity injuries clearly challenge the usefulness and reliability of existing thresholds of directly measured compartment pressures as a diagnostic tool (*13,21,25*).

Fulkerson *et al* described a combination of compartment pressure measurement and supporting

clinical evidence as the basis for operative intervention in foot compartment syndrome (*5*). Tissue pressures in excess of 30 mm Hg or within 10-30 mm Hg could be an absolute indication for fasciotomy (*5,15,17,30,33*). Until recently, the foot had been divided into four fascial compartments (*9,15,19, 30,33*). Currently, there are nine described foot osseo-fascial compartments (*3,12,18*).

Loeffler *et al* described a direct plantar approach to completely release foot fascial compartment syndrome (*9*). A dorsal approach provides minimal soft tissue dissection with direct access to the interossei compartments as well as access for fixation of metatarsal and phalangeal fractures. This produces a gradual reduction of tissue pressures and may not adequately release the calcaneal compartment (*10*).

The medial approach involving more extensive retraction and dissection is performed carefully to prevent damage to the plantar neurovascular bundle (*5,27*). The medial incision could be extended proximally to inspect the neurovascular bundle and to release the tarsal tunnel (*34*). The lateral approach releases the lateral and interossei foot compartments, minimizes deep dissection and also provides a portal for calcaneal fracture fixation (*5,15,34*). Adequate decompression of foot compartment syndrome was achieved using a medial incision and two dorsal incisions (*20*). This utilizes the desirable elements of both approaches (*10*).

Fasciotomy wounds often undergo delayed primary closure or skin grafts. It may be important to continue monitoring of compartment pressures after fasciotomy to ensure that all areas are adequately decompressed (*8*). Split-thickness skin grafts may be required in failure of secondary closure, injuries with large tissue defects, or avulsion injuries. This could be done primarily for avulsion injuries or in the delayed setting (one week after fasciotomy) (*16,35*). Ziv *et al* (*34*) described a one-stage procedure in which split-thickness excision provides immediate wound coverage after fasciotomy. This serves as a biologic dressing and reduces hospital time, but raises the risk of infection. In cases of late diagnosis, the goal of late reconstruction of the foot is to achieve a minimally painful and relatively functional plantigrade foot (*23*).

Foot compartment syndromes may contribute to diminished outcomes in the multiply injured patient due to residual physical and psychological symptoms (*31*). In a study of outcomes after lower extremity injuries from motor vehicle accidents (MVA), Read *et al* (*26*) reported that 22% of patients with foot injuries were unable to return to work after treatment while 36% had limitations with walking. In this study, four patients were reported as having returned to work after fasciotomies.

Ischaemic contracture of the quadratus plantae muscle due to high compartment pressures has been identified as the cause of toe flexion deformities following calcaneal fractures (*14*). When contracted, the muscle which inserts onto the long tendons of the flexor digitorum longus exerts a pulling effect on the extrinsic flexor tendons producing a fixed flexion deformity of the toes. Clawfoot (intrinsic minus) defects could occur due to weakness of the intrinsic muscles (lumbricals and interossei) or due to ischaemic shortening of the intrinsic muscles producing the intrinsic plus foot deformity.

Alternative options are being developed using various technologies to monitor compartment pressures and complement the diagnosis of foot compartment syndrome. These include use of biological markers (creatine kinase, myoglobin, and fatty acid-binding protein) pulsed phase locked loop ultrasound, magnetic resonance imaging (MRI), Laser Doppler flowmetry, infrared imaging, near infra-red spectroscopy, pulse oximetry, tissue ultrafiltration, skin surface hardness or pressure measurements, direct nerve stimulation, vibratory sensation testing, and somatosensory evoked potential testing (*1,7,24,29,32*).

Complications of surgical release are minimal and pale in comparison to complications of delayed treatment. Surgical sequelae include injury to the medial plantar nerve lying in the calcaneal or superficial compartment along the distal limit of the medial fasciotomy. Also, the uneven distribution of soft tissue coverage over the bone may contribute to the severe scarring seen in some cases after fasciotomy.

There is limited evidence about the causes, diagnosis, skin incisions, wound closure techniques, and functional outcomes of foot compartment

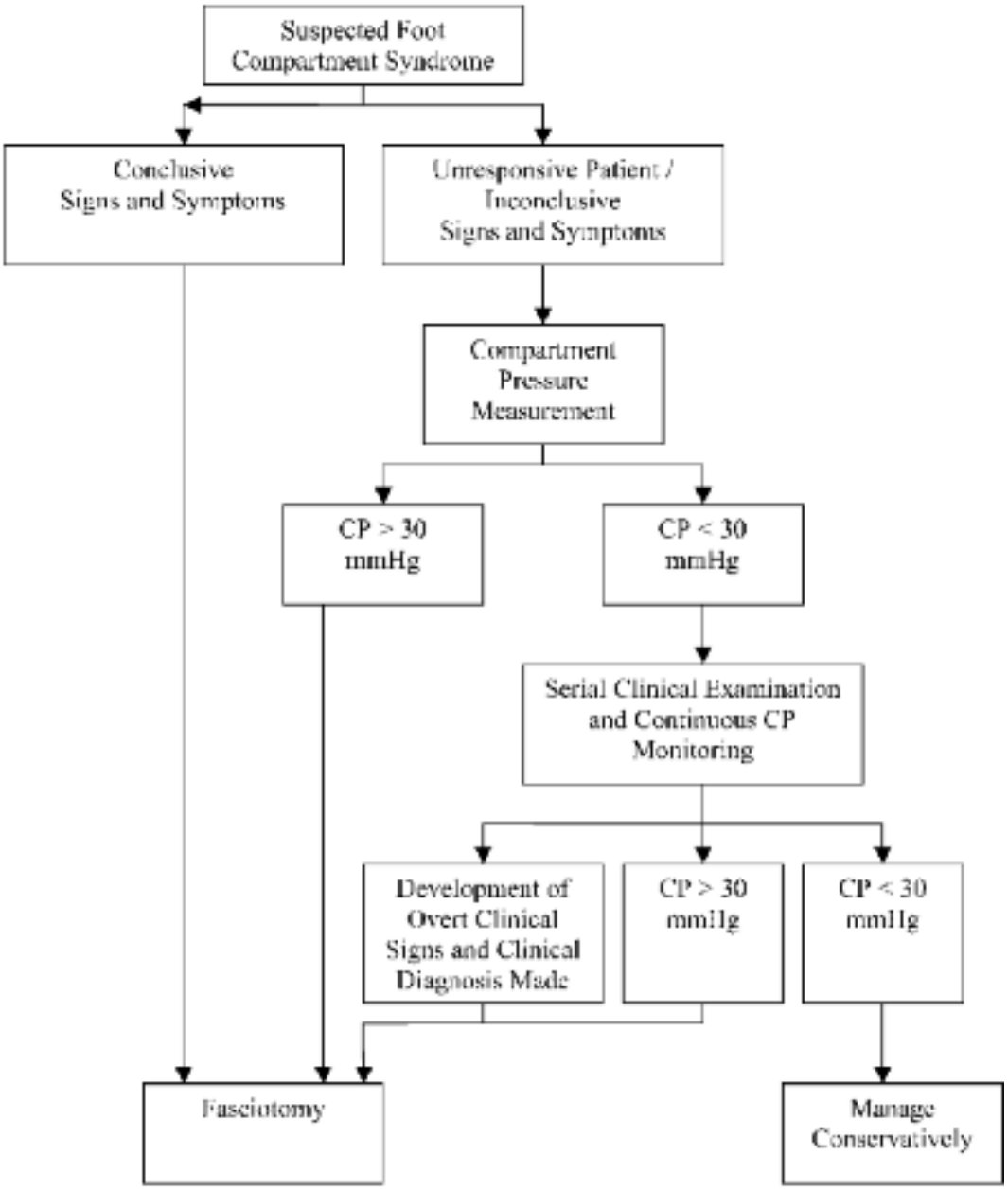

Fig. 1. — Algorithm guide for the management of foot compartment syndrome (CP = compartment pressure)

syndrome. Based on the available limited evidence, we have created an algorithm guide for clinical decision-making (fig 1). There is a need for more studies describing the treatment, management, and outcomes of compartment syndrome of the foot.

REFERENCES

1. Arokoski JP, Surakka J, Ojala T, Kolari P, Jurvelin JS. Feasibility of the use of a novel soft tissue stiffness meter. *Physiol Meas* 2005 ; 26 : 215-228.

2. **Baumhauer JF, Manoli II A.** Principles of management of the severely traumatized foot and ankle. *Instr Course Lect* 2001 ; 51 : 159-167.
3. **Botte MJ, Santi MD, Prestianni CA, Abrams RA.** Ischemic contracture of the foot and ankle : Principles of management and prevention. *Orthopedics* 1996 ; 19 : 235-244.
4. **Fakhouri AJ, Manoli II A.** Acute foot compartment syndromes. *J Orthop Trauma* 1992 ; 6 : 223-228.
5. **Fulkerson E, Razi A, Tejwani N.** Review : Acute compartment syndrome of the foot. *Foot Ankle Int* 2003 ; 24 : 180-187.
6. **Jeffers RF, Tan HB, Nicolopoulos C, Kamath R, Giannoudis PV.** Prevalence and patterns of foot injuries following motorcycle trauma. *J Orthop Trauma* 2004 ; 18 : 87-91.
7. **Lampert R, Weih EH, Breucking E *et al.*** Postoperative bilateral compartment syndrome resulting from prolonged urological surgery in lithotomy position. Serum creatine kinase activity (CK) as a warning signal in sedated, artificially respirated patients. *Anaesthesist* 1995 ; 44 : 43-47.
8. **Lewis J, Mendicino RW, Mendicino SS.** Compartment syndrome causing neuropathies. *Clin Podiatr Med* 1994 ; 11 : 593-608.
9. **Loeffler RD, Ballard A.** Plantar fascial spaces of the foot and a proposed surgical approach. *Foot Ankle* 1980 ; 1 : 11-14.
10. **Manoli II A.** Compartment syndromes of the foot : Current concepts. *Foot Ankle* 1990 ; 19 : 340-344.
11. **Manoli II A, Fakhouri AJ, Weber TG.** Concurrent compartment syndromes of the leg and foot. *Foot Ankle* 1993 ; 14 : 339-342.
12. **Manoli II A, Weber TG.** Fasciotomy of the foot : An anatomical study with special reference to release of the calcaneal compartment. *Foot Ankle* 1990 ; 10 : 267-275.
13. **McQueen MM, Court-Brown CM.** Compartment pressure monitoring in tibial fractures. The pressure threshold for decompression. *J Bone Joint Surg* 1996 ; 78-B : 99-104.
14. **Mittlemeier T, Machler G, Lob G *et al.*** Compartment syndrome in the foot after intraarticular calcaneal fractures : *Clin Orthop Relat Res* 1991 ; 269 : 241-248.
15. **Myerson M.** Acute compartment syndrome of the foot. *Bull Hosp Jt Dis Orthop Inst* 1987 ; 47 : 251-261.
16. **Myerson M.** Split-thickness skin excision : Its use for immediate wound care in crush injuries of the foot. *Foot Ankle* 1989, 10 : 54-60.
17. **Myerson M, Manoli A II.** Compartment syndromes of the foot after calcaneal fractures. *Clin Orthop Relat Res* 1993 ; 290 : 142-150.
18. **Myerson MS.** Diagnosis and treatment of compartment syndrome of the foot. *Orthopedics* 1990 ; 13 : 711-717.
19. **Myerson MS.** Experimental decompression of the fascial compartments of the foot. The basis for fasciotomy in acute compartment syndromes of the foot. *Foot Ankle* 1988 ; 8 : 308-314.
20. **Myerson MS.** Management of compartment syndromes of the foot. *Clin Orthop Relat Res* 1991 ; 271 : 239-248.
21. **Ovre S. Hvaal K, Stromsoe K, Nordsletten L, Skjeldal S.** Compartment pressure in nailed tibial fractures. A threshold of 39 mm Hg for decompression gives 29% fasciotomies. *Arch Orthop Trauma Surg* 1998 ; 118 : 29-31.
22. **Perry MD, Manoli II A.** Foot compartment syndrome. *Orthop Clin North Am* 2001 ; 32 : 103-111.
23. **Perry MD, Manoli II A.** Reconstruction of the foot after foot or leg compartment syndrome. *Foot Ankle Clin* 2006 ; 11 : 191-201.
24. **Phillips JH, Mackinnon SE, Beatty SE, Dellon AL, O'Brien JP.** Vibratory sensory testing in acute compartment syndromes : A clinical and experimental study. *Plast Reconstr Surg* 1987 ; 79 : 796-801.
25. **Prayson MU, Chen JL, Hampers D *et al.*** Baseline compartment pressure measurements in isolated lower extremity fractures without clinical compartment syndrome. *J Trauma* 2006 ; 69 : 1037-1040.
26. **Read K, Kufera JA, Dischinger PC *et al.*** Life-altering outcomes after lower extremity injuries sustained in motor vehicle crashes. *J Trauma* 2004 ; 57 : 815-823.
27. **Santi MD, Botte MJ.** Volkmann's ischemic contracture of the foot and ankle : evaluation and treatment of established deformity. *Foot Ankle Int* 1995 ; 16 : 368-377.
28. **Sarrafin SK.** Fasciotomy of the foot : An anatomical study with special reference to the release of the calcaneal compartment. *Foot Ankle* 1990 ; 11 : 54-55.
29. **Shadgan B, Menon M, O'Brien PF, Reid WD.** Diagnostic techniques in acute compartment syndrome of the leg. *J Orthop Trauma* 2008 ; 22 : 581-587.
30. **Shereff MJ.** Compartment syndromes of the foot. *Instr Course Lect* 1990 ; 39 : 127-132.
31. **Turchin CD, Schemitsch EH, McKee MD, Waddell JP.** Do foot injuries affect the functional outcome of multiply injured patients ? *J Orthop Trauma* 1999 ; 13 : 1-4.
32. **Wassenaar EB, Van Den Brand JGH.** Reliability of near-infrared spectroscopy in people with dark skin pigmentation. *J Clin Monit Comput* 2005 ; 19 : 195-199.
33. **Whitesides TE, Haney TC, Morimoto R, Harada H.** Tissue pressure measurement as a determinant for the need of fasciotomy. *Clin Orthop Relat Res* 1975 ; 113 : 43-51.
34. **Ziv I, Mosheiff R, Zeligowski A *et al.*** Crush injuries of the foot with compartment syndrome. Immediate one-stage management. *Foot Ankle* 1989 ; 9 : 185-189.
35. **Ziv I, Zeligowski AA, Mosheiff R *et al.*** Split thickness skin excision in severe open fractures. *J Bone Joint Surg* 1988 : 70-B : 23-26.