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RESEARCH ARTICLE

MUSCLE COMPARTMENT PRESSURE THRESHOLD AND OUTCOME; ASSESSMENT OF CRITICAL PRESSURE RANGE IN TRAUMATIC AND VASCULAR LOWER EXTREMITY INJURIES

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ABSTRACT

Background: Muscle compartment syndrome is a known morbid complication of physiologic and mechanical lower extremity trauma. Determining the critical range in different centers for optimal management is suggested.

Methods: In a two sectional prospective clinical study, 149 referral patients of lower extremity trauma and vascular injuries were recruited for compartment pressure assessment during eleven months by Whiteside apparatus. Compartment pressures and ΔP simultaneously recorded in admission, pre and post operative and before fasciotomy and discharge in order to determine critical range, the outcome and comparing for correlations.

Results: Of 149 patients, 117 cases of normal recovery, 14 cases of activity deficits, 14 fasciotomized patients and four amputations were detected. Causes were 122 trauma cases and 27 thrombo-embolic events. Pressure range was 12- 46 mmHg and ΔP was ranged 58-25. There were significant correlations between extremity outcomes and compartment pressure in all defined periods (P=<0.02). ΔP was not correlated except in post operation time (P=<0.001). Significant correlation was found between outcome and fluid resuscitations (P=<0.001). Fasciotomized patients were presented significant correlations with liquid resuscitation, operative duration, compartment pressures and ΔP at defined periods (P=<0.001). Critical thresholds were found similar to medical literature, compartment pressure about 35- 40 mmHg and ΔP lower than 20 mmHg below diastolic pressure.

Conclusion: regarding the results, we conclude that frequent simultaneous compartment pressure and ΔP recording alongside clinical examination is necessary. Even without clinical presentation, fasciotomy is advocated in critical levels. On-time fasciotomy may be final therapeutic key but do not completely support the outcome.

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INTRODUCTION

Muscle compartment is a functional restricted closed chamber, highly dependent on muscle movements, circulation, drainage and its boundary relationships that produce its compliance. Increased Intra Compartment Pressure (ICP) leads to clinical Acute Compartment Syndrome (ACS), which in turn results in progressive impairment of cellular and physiologic function. Ischemic Compartment has first recognized in 1881 by Volkmann. He explained paralysis with late contracture followed by compressing neuro-vascular bundle of traumatic extremities (1). Now, although there is extensive progression, but still no diagnostic biomarker or co-enzyme is discovered for a timely approach.

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Therefore, diagnosis and treatment have been relied upon clinical assessment and full physical examinations (2-4). ICP measurement is a complementary interfering method for assisting accurate and abrupt diagnosis in order to achieve faster release and prevent associated progressive damages. Normal pressure in different studies is approximately 0-10 mmHg (3). The rise in ICP levels over the level of arterial pressure ends in ischemia followed by circulatory abruption. In this circumstance, muscle cell necrosis and nerve paralysis occurs in less than couple of hours resulting in gangrene and extremity loss (5,3). Although, the optimum pressure range is about 20 mmHg, it may differ in some circumstances. Measured ICP of about 30 mmHg or more have been postulated that is alarming and requires surgical releasing intervention (3). Prompt fasciotomy until excluding the main causes is essential and presumed a safe procedure that prevents a permanent neurological deficit especially in vascular

thrombotic accidents (6). According to the golden time, in releasing the compression (<3 hours, 1-2 hours optimum) (5,3), nervous and muscle symptoms are reversible and lower the risk of amputation by at least a third. Nevertheless, ICP can still be resisted and ACS may become stable in spite of fasciotomy, leading to the progression of compression and ultimate limb loss. Such rare complication may occur due to incomplete fasciotomy or late fulfilling as the eventual outcome, which directly related to the interval between diagnosis and definite treatment (7). Although, a clear correlation between delaying (22-23 hours) and clinical outcome have not been achieved (8). Accordingly, young muscular patients with accompanying vascular injuries, comminuted fractures especially tibial types and extremity trauma with massive transfusion, require faster and accurate fasciotomy (3). Therefore, knowledge of definite range of muscle compartment releasing time, defined as "critical range" presume crucial in different circumstances and every medical center. The present part of sectional study attempts to identify territorial critical ranges of ICP in traumatic lower extremity and vascular injured patients who were required prompt treatment and also investigates the associated outcome of their treatment in relation to successive compartment pressure measurements during management.

MATERIALS AND METHODS

This study was the main first part of a two sectional prospective clinical trial for investigating ICP in patients of lower extremity traumas. Referral patients admitted to the trauma divisions (orthopedic, surgical, vascular) of three affiliated hospitals of Ahwaz Jundishapour University of Medical Sciences that are referral hospitals, were enrolled onto the clinical trial during a period of eleven months between May and April 2014. Informed written consents was acquired for participation in the study based on ethical approval conform to the guidelines of 1975 declaration of Helsinki and approved research project of Ahwaz University of Medical Sciences institution, No: U-92050, faculty registration No: D/826. Inclusion criteria were: stab or blunt vascular injuries of lower extremity, symptomatic moderate to severe lower extremity blunt trauma, open and closed comminuted fracture injuries with or without vascular trauma, live lower extremity arterial thrombo-emboli accidents that were treatable. Patients with non-acute and mild symptomatic traumas and crush injuries that scheduled for amputation were excluded from the study as exclusion criteria. In this part of the study, ICP were measured using the Whiteside apparatus and it's technique prepared by mercury manometer, on admission, prior to the main operation for trauma management, 12-24 hours after the procedure and prior fasciotomy 'if was required' and prior to discharge in order to determine critical ICP threshold and the extremity outcome. Treatment modality, quantity and type of water and electrolyte therapy alongside all transfusions, time past from the injury, physical examinations, blood pressure and other vital signs for trauma management protocol were recorded. Data were registered on a prepared questionnaire and were analyzed with T test, Chi-square and ANOVA (post hoc) tests through SPSS software. We considered the level of significance α of 0.05.

Table 1. Frequency and outcome of patients and fasciotomized cases in the study

Total Patients Outcome 119 males , 30 females	Frequency (Total 149)	Fasciotomy Outcome Frequency, 14 of 149
Complete saved activity **	117	4
Decreased activity *	14	6
Fasciotomies	14	
Amputations	4	4

Table 1, **Complete saved activity defined as normal recovered patients without complication. *Decreased activity attributes to the patients recovered with involving in one or relatively all: paresthesia, walking deficit, drop foot.

Table 2. Demography, Type and frequency of injuries, management and ICP with ΔP ranges in Total patients of the study

Gender	119 male (79.9%) , 30 female (20.1%)	
Age (years)	Mean = 36.52 (Min= 11, Max= 88)	
Injury types (Cases)	Blunt trauma	116
Calves, femuro-tibial types	Closed comminuted Fx	74
	Open Fx	35
	Fx + Vascular deficit (Ilio-femoral-popliteal)	7
	Penetrating trauma	6
	Arterial thrombo-embolism (Ilio-femoral-popliteal)	27
Resuscitation	Fluid support (Ringer, Lactated ringer, N/S) (Mean=1243ml, Min=0, Max=6500, SD=1110.53)	137
	Fluid + Blood transfusion	9
	No Fluid, No Blood	3
Operation times (Hours)	Past from injury, mean=26.90 (Min=4, Max=144, SD= 21.43)	
	Procedure duration, mean= 1.41 (Min=1,Max=5,SD=0.765)	
Mean ICP (Intra Compartment Pressure)	Admission	12.04 (Min=2, Max=25, SD=4.998)
	Before main Op*	15.38 (Min=4, Max= 30, SD=5.505)
	Post main Op	19.22 (Min=7, Max= 45, SD=8.758)
	Before Fasciotomy	46.00 (Min=35, Max= 53, SD=5.870)
Mean ΔP (Diastolic pressure minus ICP)	Admission	58.23 (Min=28, Max=88, SD=11.581)
	Before main Op	59.27 (Min=34, Max= 91, SD=10.660)
	Post main Op	56.74 (Min=25, Max=82, SD=10.561)
	Before Fasciotomy	24.71 (Min=18, Max= 31, SD=4.027)

Table 2 . *Main Op, attributed to the main operation for patient rehabilitation. Fx (fractures), Min (minimum), Max (maximum), SD (standard deviation), ΔP (delta P).

RESULTS

Overall 149 patients were entered onto the trial with an average age of 36.5 years (Min=11, Max=88, SD=17.9). 30 patients (20.13%) were females and 119 others (79.86%) were males. 122 cases (81.9%) for trauma and 27 cases (18.1%) for ischemia due to thrombo-embolism participated. From 149 patients, 131 cases saved and returned to activity [of 131 patients, 117 (78.52%) cases fully recovered to normal status Without complication (mean ICP at admission: 11.63 mmHg, prior to the main operation (Op) 14.99, post main Op 17.83 and before discharge 12.18); whereas, 14 cases (9.4%) had complications and some remained drop foot, paresthesia and walking deficits]. From remainders, 14 patients eventually were fasciotomized (of fasciotomized cases 4 patients recovered normally and 6 patients complicated as mentioned above and 4 cases had finally amputation of foot and toes). 4 (2.7%) other patients of vascular accidents and trauma had also

Table 3. Characteristics of fasciotomized patients in the study

Gender	9 male (64.3%) 5 female (35.7%)	
Causes	9 (64.3%) Blunt trauma	
	4 (28.57%) Arterial emboli	
	1 (7.14%) Gunshot penetrating injury	
Age (years)	Mean = 40.71 (Min= 21, Max= 66)	
Distal pulses	5 = (+) 9 = (−)	
Injuries (cases)	Fx + Vascular deficit	4
	Closed Fx	3
	Open Fx	1
	Without Fx, with vascular deficit	1
	Without Fx, without vascular deficit	1
	Arterial embolism	4
Resuscitation	Fluid support	3
	Fluid + Blood transfusion	8
	No Fluid, No Blood	3
Mean ICP	Admission	16.00 (Min=8, Max=23, SD=4.91)
	Before main Op*	19.14 (Min=9, Max= 30, SD=5.73)
	Post main Op	33.31 (Min=22, Max= 45, SD=7.26)
	Before Fasciotomy	46.00 (Min=35, Max= 53, SD=5.87)
Mean ΔP (Diastolic pressure minus ICP)	Admission	44.71 (Min=28, Max=64, SD=12.30)
	Before main Op	50.50 (Min=34, Max= 68, SD=9.23)
	Post main Op	37.84 (Min=25, Max=52, SD=8.75)
	Before Fasciotomy	24.71 (Min=18, Max= 31, SD=4.02)

Table 3. *Main Op, attributed to the main operation for patient rehabilitation. Fx (fractures), Min (minimum), Max (maximum), SD (standard deviation). ICP (Intra Compartment Pressure), ΔP (delta P).

Table 4. Correlations of extremity outcome with ICP and ΔP in defined periods (refer supplementary file)

Variables	P values
ICP at the first visit	0.003
ICP before operation	0.027
ICP 12-24 hours after operation	0.000
ICP before fasciotomy	0.159
ICP before discharge	0.003
ΔP at first visit	0.077
ΔP before operation	0.072
ΔP after operation	0.000
ΔP before fasciotomy	0.237

Table 5. Correlations of variables with required fasciotomy in the trial (refer supplementary file)

Variants	P values
Fluid resuscitation	0.000
Time from injury until operation	0.236
Operation duration	0.000
ICP at Admission	0.002
ICP before operation	0.007
ICP after operation	0.000
ΔP at Admission	0.000
ΔP before operation	0.001
ΔP after operation	0.000

Table 6. Outcome correlated variables in the study (refer supplementary file)

Variants	P values
Age	0.241
Fluid resuscitation	0.000
Interval time (injury till surgery)	0.013
Operation duration	0.001

below knee amputations (Table 1). Mean ΔP (diastolic pressure minus ICP) in overall 149 cases were 58.23 in the first visit, 59.27 before main Op, 56.74 post-main Op and before fasciotomy 24.71. Of total 149 cases, 14 (9.3%) patients underwent fasciotomy due to their ICP, clinical presentations and surgeon confirmation. Prior to fasciotomy, mean ICP was 46 mmHg (Min= 35, Max=53, SD=5.8) and mean ΔP was 24.7 (Min=18, Max=31, SD=4.02).

From 14 fasciotomized patients, 4 total recovery, 4 amputations and 6 restricted activities were achieved with mean ICP=12.04 mmHg in admission, before main Op= 15.38, post main Op= 19.22, before fasciotomy with ACS= 46 mmHg and before discharge 12.18 mmHg (Table 2). Of 14 fasciotomized patients, 4 cases (28.57%) were due to arterial thrombo-emboli, 9 (64.3%) of blunt trauma and one case (7.14%) of gunshot penetrating injury.

Table 4. Correlations of extremity outcome with ICP and ΔP in defined periods

Variables		Sum of squares	Df	Mean square	F	Sig.
ICP at first visit	Between groups	285.269	2	142.634	6.102	0.003
	Within groups	3412.490	146	23.373		
	Total	3697.758	148			
ICP before operation	Between groups	216.461	2	108.231	3.703	0.027
	Within groups	4238.349	145	29.230		
	Total	4454.811	147			
ICP 12-24 hours	Between groups	3276.544	2	1638.272	29.946	0.000
After operation	Within groups	7768.349	142	54.707		
	Total	11044.938	144			
ICP before fasciotomy	Between groups	127.417	2	63.708	2.186	0.159
	Within groups	320.583	11	29.144		
	Total	448.000	13			
ICP before discharge	Between groups	102.417	1	102.417	9.084	0.003
	Within groups	1499.465	133	11.274		
	Total	1601.881	134			
ΔP at first visit	Between groups	683.938	2	341.969	2.605	0.077
	Within groups	19166.304	146	131.276		
	Total	19850.242	148			
ΔP before operation	Between groups	594.018	2	297.009	2.673	0.072
	Within groups	16113.171	145	111.125		
	Total	16707.189	147			
ΔP after operation	Between groups	3163.047	2	1581.524	17.411	0.000
	Within groups	12898.511	142	90.835		
	Total	16061.559	144			
ΔP before fasciotomy	Between groups	48.607	2	24.304	1.648	0.237
	Within groups	162.250	11	14.750		
	Total	210.857	13			

Table 5. Correlations of variables with required fasciotomy in the trial.

Variants		Sum of Squares	Df	Mean Square	F	Sig.
Fluid resuscitation	Between Groups	47684955.257	1	47684955.257	52.046	0.000
	Within Groups	1.34748	147	916213.152		
	Total	1.82438	148			
Time from injury	Between Groups	649.320	1	649.320	1.418	0.236
until operation	Within Groups	65959.338	144	458.51		
	Total	66608.658	145			
Operation duration	Between Groups	9.993	1	9.993	19.225	0.000
	Within Groups	74.850	144	0.520		
	Total	84.842	145			
ICP at Admission	Between Groups	242.277	1	242.277	10.307	0.002
	Within Groups	3455.481	147	23.507		
	Total	3697.758	148			
ICP before operation	Between Groups	219.126	1	219.126	7.553	0.007
	Within Groups	4235.684	146	29.012		
	Total	4454.811	147			
ICP after operation	Between Groups	2833.835	1	2833.835	49.353	0.000
(12-24 Hours)	Within Groups	8211.103	143	57.420		
	Total	11044.9380	144			
ΔP at Admission	Between Groups	2821.903	1	2821.903	24.361	0.000
	Within Groups	17028.339	147	115.839		
	Total	19850.242	148			
ΔP before operation	Between Groups	1189.353	1	1189.353	11.190	0.001
	Within Groups	15517.836	146	106.287		
	Total	16707.189	147			
ΔP after operation	Between Groups	5100.351	1	5100.351	66.539	0.000
	Within Groups	10961.207	143	76.652		
	Total	16061.559	144			

Mean quantity of fluid resuscitation until stability was 1243cc (Min=0, Max=6500, SD=1110) in all 149, and was 3000cc (Min=0, Max=6500, SD=2047 ml) in fasciotomized patients (Table 3). Average time difference between presence of injury and operation was 26.9 hours (Min=4, Max=144, SD=21.43) in all cases and 20.43 hours (Min=6, Max=72, SD=16.97) in fasciotomized patients. Average duration of surgical procedures was 1.41 hours (Min=1, Max=5, SD=0.76) in all and 2.21 hours (Min=1, Max=4, SD=1.31) in patients with fasciotomy. There were no statistical correlations between extremities and the type of injury (p=0.70), existence of pulses (P=0.68), type of fracture (P=0.06), and the interval between injury and operation (P=0.22), and operation duration (P=0.41) in fasciotomized patients.

recovered patients (P=0.24). Mean fluid resuscitation in amputated cases was 3250 ml, in patients with decreased activity 1803 ml and in others with normal outcome 1122ml (P=<0.001). Average time difference between the trauma and operation in amputations was 20 hours in comparison with 25 hours in normal recovered and 42 hours in decreased activity cases (P=0.013). Mean operation durations in amputations, activity deficit, normal outcomes were 2.75, 1.57 and 1.36 hours respectively (P=0.001) (Table 6).

DISCUSSION

Knowledge of the pressure status is the key factor in succeeding management of any compartment syndrome.

Table 6. Outcome correlated variables in the study

Variants		Sum of Squares	Df	Mean Square	F	Sig.
Age	Between Groups	920.452	2	460.226	1.436	0.241
	Within Groups	46776.756	146	320.389		
	Total	47697.208	148			
Fluid resuscitation	Between Groups	22425165.635	2	11212582.818	10.235	0.000
	Within Groups	1.599E8	146	1095500.842		
	Total	1.824E8	148			
Interval time (injury till surgery)						
	Between Groups	3948.764	2	1974.382	4.506	0.013
	Within Groups	62659.894	143	438.181		
	Total	66608.658	145			
Operation duration	Between Groups	7.984	2	3.992	7.428	0.001
	Within Groups	76.858	143	0.537		
	Total	84.842	145			

The ICP levels in patients admitted due to arterial embolism and ischemia, at admission and before the main operation were lower than patients admitted for blunt trauma and penetrating injuries (P<0.001), but after operation and before discharge (p<0.001) and before fasciotomy (P=0.343) they had higher ICP. Correlation of ΔP with required fasciotomy and the type of injury was significant only at first visit on admission and after operation (P<0.001). Outcome of extremity was directly correlated to the ICP in all defined periods (P=<0.02), except in measurements before fasciotomy (P=0.159). ΔP was not correlated to these periods except after operation time (Table 4). Patients with full recovery to normal activity had higher ΔP compared to those with complicated outcome. These conditions did not present meaningful correlation except in cases following the 12-24 hours post operation (P=<0.001) (Table 4). From 14 cases that required fasciotomy, 8 cases required blood transfusion in addition to fluid resuscitation. However, in non-fasciotomized patients only one case was transfused (P=<0.001).

Mean administered fluid volume, operation duration and ICP in all recorded times of measurements were found to be higher in fasciotomized cases (P=<0.007). ΔP at the same times was lower in the fasciotomized patients compared to the non-fasciotomized group (P=0.001). Most of pulseless cases (n=9) were within fasciotomized patients and most of fasciotomized cases (n=8) received blood transfusions. There were significant correlations between liquid resuscitation, operative duration, ICP and ΔP at defined periods with fasciotomy requirement. The interval between injury and operation did not correlate in this population (Table 5). In regards to results, there was no significant correlation between the average ages in amputated patients compared to cases of decreased activity and fully

Delayed diagnosis, hesitations due to insidious clinical presentation, and prolonged management for high severe basic injuries that strays the surgeon from total control, can lead to devastating complications and even death; especially in unconscious victims or mentally retarded cases. Although, physical examination is still the best practice, insisting on only clinical presentation now, would not be excused ethically. There are simple available appropriate measurement apparatus for utilizing such as Whiteside or provided commercial probes that are proved to be effective ambulatory applicants for measurement of ICP in any place and any time (9).

Basically, ICP level of higher than 35mmHg, pressure recording of 20 mmHg below the diastolic pressure or 30 mmHg below the main arterial pressure (10) which defined as ΔP index <30 mmHg, have postulated critical in medical literature and advise immediate interventions (2,3,11-13). Our data demonstrated that the mean ICP at admissions and at 12-24 hours post operations were variable between 11.63 to 17.83 mmHg; though, strangely, pressures of approximately 40-45 mmHg were well tolerable in some patients with no clinical symptoms. Based on the ICP, ranges in amputated cases were higher compare to the patients with decreased activity status (paresthesia, walking deficit, drop foot) and so decreased activity patients had higher ICP levels compare to the fully recovered cases (P=<0.02). Vice versa, ΔP was also lower in amputated cases compare to who were involved in complicated decreased activity; and in complicated cases also were lower than the recovered patients, except before fasciotomy. Since the data were correlated significantly with post operation pressure releasing (P=<0.001), findings demonstrate that progressive high compartment pressure along with lower ΔP, could lead to serious complications if compartment was not

being decompressed. Overall, recorded pressures in mentioned situations of the study were shown that ICP of higher than 40 mmHg and ΔP of lower than 25 mmHg similar to the literature, were actually critical. Usually, the obtained rang has been symptomatic, but we believe sometimes, even in the absence of clinical presentations critical levels deserve fasciotomy as an acceptable judgment in preventing the majority of related unpleasant complications. Our aforementioned findings are in conformity with previously published studies (2,3,11-13).

Furthermore, the results of the trial suggested that blood pressure in the time of ICP measurement and calculation of ΔP should be considered and corrected if there was any depleted sustained hypotension. Indeed, we have found that in hypotension, ΔP had shown as low as even approximately 15-20 mmHg in existence of an acceptable range of ICP in pre-operative periods and admission times that fasciotomy was not indicated or required. In fasciotomized patients, significant differences that were presented according to the existed correlation between the fasciotomy requirement and volume of liquid administration and blood transfusion (P=<0.001) were also in keeping with the previous findings by Prayson (4) and Kosir et al (14). Accordingly, this advocated that unstable circulatory volume status, which requires acute high volume correction by crystalloids and blood transfusions, is an important predisposing risk factor that increases susceptibility of producing known interstitial edema that induce ICP rising. Besides, prolonged surgical procedures and high ICP in admission (pre and post operative phase) and reduction in ΔP at the same times were found correlated with other important risk factors for expecting fasciotomy or concomitant complication.

Lack of meaningful correlation of extremities outcome with the type of injuries, and further high ICP range without clinical presentation, practically, raise the probability of a second interfering process such as 'reactive inflammatory phenomena' accompanied by the main mechanical insult that was untruthfully intensified rising of ICP. Similarly, significant correlation of outcome with volume of liquid resuscitation and duration of surgery ($P \leq 0.01$), explain the worsened extremity recovery and resistant soft tissue swelling and again subsequent ICP increasing. Examples of such an observations are patients who in the study did not require fasciotomy in post thrombo-embolectomy follow up in comparison with traumatic group. They were shown to have lower ICP in pre-operative phase versus higher ICP (ICP = 45 mmHg) post operatively. Trauma patients were presented less tolerance of clinical threshold in the study than patients with arterial ischemia alone and vice versa. Perhaps, decreased muscular mass and old ages may be implicated in the tolerance of embolectomized cases. Hence, we presumed traumatic limb contains a biphasic reaction that is not seen in non-traumatic injury limbs as mentioned earlier as probable reactive inflammatory phase. As an important clue, in spite of wide variability in lower extremity compartment pressures, because statistically comparison of clinical status and outcome with their etiology and causes were refused any correlation; therefore, ICP pressure may interpret as an independent condition that apart from it's producing factors, necessitates to approach individually. Consequently, measurement needs to be applied in all suspicious and swollen extremities at all defined periods, aside from their etiology, clinical status and independent from main patient's treatment. We have found the Whiteside method to be practical and suggest that pressure measurement be scheduled and educated in all trauma centers as a standard method. It is important to emphasize that pressure threshold is not solely adequate, and ΔP calculation should also be accompanied, with reservation that the obtained thresholds yet would not be an accurate reflection for ACS. However, admittedly, these data are suitable guideline when collected together with clinical presentations. On time fasciotomy may be final therapeutic key but does not entirely support injury outcome. However, "not as prophylaxis", being liberal to decide performing an indicated fasciotomy should account a crucial issue and certainly possess promising effects. Finally, we conclude that simultaneous measurement of ICP and ΔP calculation necessitate to be considered in all trauma centers and recommend to be scheduled in a routine protocol for extremity injuries and be educated practically. Fasciotomy should attempt to be performed in coincided ICP range of more than 35-40 mmHg with ΔP less than 30 mmHg below the main pressure or with more accuracy less than 20 mmHg below diastolic pressure as a confirmed critical level during the trial and medical literature. However, acceptance of fasciotomy morbidity is appreciated against preserving a non-functional extremity; though, the outcome will not be completely supported.

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