European Journal of Trauma and Emergency Surgery (2019) 45:493–497
https://doi.org/10.1007/s00068-019-01082-9

ORIGINAL ARTICLE

Compartment pressures in children with normal and fractured lower extremities

Hannah Rachel Bussell[1] · Christoph Alexander Aufdenblatten[2] · Ulrike Subotic[1] · Markus Kalisch[3] · Georg Staubli[4] · Daniel Max Weber[5] · Sasha Sasha Tharakan[1]

Received: 13 October 2018 / Accepted: 30 January 2019 / Published online: 4 February 2019

Abstract

Purpose Needle manometry is a tool to confirm suspected acute compartment syndrome (ACS). There is scarce evidence of normal pressure values of the lower extremities in children. The aim of this study is to assess the normal compartment pressures in non-injured lower extremities of children.

Methods This prospective study included children up to the age of 16 years with lower extremity fractures that needed reduction. Between June 2009 and August 2015, 20 children were included. We used needle manometry to measure the pressures in the superficial (SPC), deep posterior (DPC) and in the anterior compartments (AC) on both the lower legs.

Results On the healthy leg, the mean compartment pressure was 15.15 mmHg in the AC (range 7–30 mmHg), 14.32 mmHg in the SPC (range 8–24 mmHg) and 13.00 mmHg in the DPC (range 4–21 mmHg). On the injured leg, the mean compartment pressure was 24.07 mmHg in the AC (range 5–40 mmHg), 17.21 mmHg in the SPC (range 7–29 mmHg) and 17.13 mmHg in the DPC (range 6–37 mmHg). We found a perfusion gradient (diastolic blood pressure—compartment pressure) < 30 mmHg in at least one compartment of the fractured and healthy leg in 13 patients. Five patients underwent fasciotomy for suspected ACS and their data was excluded for the injured leg.

Conclusion We could show that children have higher normal compartment pressures than adults in the lower leg. They seem to be able to tolerate higher absolute compartment pressures and lower pressure gradients before ACS occurs. More studies are needed to make a final statement on tolerable compartment pressures in children.

Keywords Compartment pressure · Pediatric · Compartment syndrome · Lower extremity

Introduction

Acute compartment syndrome (ACS) occurs when pressure increases within a confined closed fascial space causing subsequently reduced blood flow and tissue perfusion that may lead to ischemic pain and possible soft-tissue damage [1]. ACS is a well-known entity amongst trauma surgeons and its treatment—a fasciotomy—has been well studied since the original publication by Richard von Volkmann in 1881 and accepted till this day as the appropriate treatment [2]. Its diagnosis, however, is not as straightforward, especially in pediatric patients. Whereas the best-known, yet overall unreliable, clinical signs "The 5 Ps"—pain, pallor, paraesthesia, pulselessness, and paralysis—are readily assessed in adult patients, this is difficult in children [3, 4]. Bae and colleagues showed that 90% of their pediatric population with ACS due to fractures presented with pain, however, less than 40% had pain and two additional classic clinical symptoms. Increased analgesic requirement, anxiety and agitation are possibly more precise clinical indicators for the presence of ACS in children [3].

A further diagnostic approach to ACS is compartment pressure measurement. Described by Whiteside et al. in

✉ Hannah Rachel Bussell
hannah.bussell@kispi.uzh.ch

1 Department of Pediatric Surgery, General and Thoracic Surgery, University Children's Hospital Zurich, Steinwiessstrasse 75, 8032 Zurich, Switzerland

2 Trauma and Orthopaedic Surgery, University Children's Hospital Zurich, Zurich, Switzerland

3 Seminar for Statistics, ETH Zurich, Zurich, Switzerland

4 Department of Emergency Medicine, University Children's Hospital Zurich, Zurich, Switzerland

5 Pediatric Hand Surgery, University Children's Hospital Zurich, Zurich, Switzerland

1975 it has since been used as a valuable objective diagnostic supplement [5]. Many debates over the cut-off pressure above which a fasciotomy is necessary have been held. Some authors have proposed absolute pressure values over 30–45 mmHg to be the cut-off for a fasciotomy to avoid ACS [6, 7]. Other authors have suggested the use of a differential pressure (Δp = diastolic blood pressure–compartment pressure) to assess the need for a fasciotomy. However, these values were studied on adult populations and are used widely for children as well because there are no standard values for children. There is scarce evidence as of what a normal compartment pressure in children is with only two studies have being published on this subject [8, 9]. In general, the diagnosis of ACS is made clinically. Many authors recommend invasive pressure measurement, regardless of the age of the patient, to have an objective measurement method for the confirmation of a suspected ACS.

The aim of this study is to assess the normal compartment pressures in non-injured lower extremities of children. To this end, we sought to quantify the maximum tolerable compartment pressures in fractured lower legs, thus establishing a baseline and providing guidance in evidence based decision making to evaluate children with suspected ACS.

Materials and methods

This prospective study included healthy children up to the age of 16 years with lower extremity fractures that needed reduction under anesthesia with or without osteosynthesis. Patients with bilateral fractures of the lower extremities, patients operated later than 24 h post injury and patients who had a fasciotomy due to suspected ACS were excluded (Table 1).

Between 06/2009 and 08/2015, 20 children were included. After obtaining a signed consent from the parents, all patients were brought to the operating room and had bilateral compartment pressure measurement under general anesthesia, fully relaxed and in supine position. Pressures were measured using a standardized method of simple needle manometry. Several techniques for compartment pressure measurement have previously been described, and assuming correct use, show equal effectiveness. These include: slit catheter, wick catheter, micro tip pressure probe, and needle manometer insertion [10, 11]. Needle manometry is readily available, inexpensive, and accurate. We, therefore, chose needle manometry with the Stryker Pressure Monitor® (Kalamazoo, MI/USA) for our intraoperative measurements. All measurements were performed by experienced attendings. Special care was taken to place the lower leg in a standardized and relaxed position to avoid false positive elevated compartment pressures (Fig. 1). We measured the pressures in the anterior, superficial posterior and deep posterior compartments on both lower legs before surgery. We were instructed by the local Medical Ethics Committee not to measure the pressures in the lateral compartment to minimize the risk of inadvertently injuring the superficial peroneal nerve. The insertion site for the 18 Gauge side ported needle was between the proximal and middle third of the lower leg on the anterior and posterior side, respectively. After zero balancing, the needle was inserted in a 45° angle into the corresponding compartment and we injected 0.3 ml

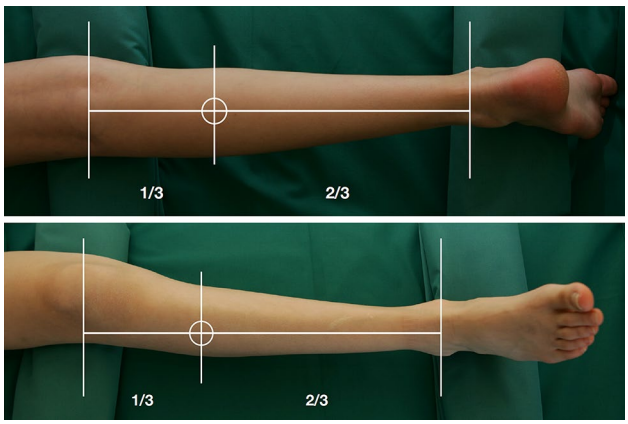

Fig. 1 Positioning of the lower leg for compartment pressure measurements of the anterior (above) and posterior (below) compartments. The site of needle entry is marked by the circled cross

Table 1 Compartment pressure values (mmHg) in 5 patients who underwent fasciotomy for ACS and whose values were, therefore, excluded from the study of the fractured leg

Patient	Fractured AC	Δp fractured AC	Fractured SPC	Δp fractured SPC	Fractured DPC	Δp fractured DPC
1	40	3	16	27	17	26
2	40	– 3	21	16	29	8
3	26	3	24	5	24	5
4	37	2	15	24	31	8
5	27	48	20	55	30	45

Delta p (Δp mmHg) represents the difference between the diastolic blood pressure and the compartment pressure value

AC anterior compartment, *SPC* superficial posterior compartment, *DPC* deep posterior compartment

of normal saline. Once the equilibrium state was reached, the pressure was read off the monitor. The pressure measurements were made before closed reduction of the fractured leg. The systolic and diastolic blood pressures were measured using a cuff at the time of compartment pressure measurement.

All patients were admitted and hospitalized until pain was well controlled with oral analgesics. All patients were seen 3 months postoperatively in clinic. Wound and fracture healing, as well as motor and sensory function were assessed. A structured telephone interview 11–83 months after surgery was performed, during which patients were asked specific questions regarding pain, motor and sensory function, scarring and potential problems with the insertion sites that were used for the compartment pressure measurements.

The mean pressures between compartments were analyzed using a Wilcoxon-Pratt Signed-Rank Test. For the relationship between age and pressure, a correlation test was used (based on Pearson's correlation). For the relationship between pressures of different compartments within the same leg, simple linear regression with prediction intervals was used.

For one patient there was no available compartment pressure measurement for the anterior compartment, neither on the fractured side nor on the healthy side. He was included in the study, yet therefore, all calculations concerning the anterior compartment were made with one patient less compared to the posterior compartments ("list-wise deletion" as recommended for small numbers of missing values) [12].

Our local Medical Ethics Committee approved this study.

Results

Our 20 patients consisted of 16 boys and four girls with a mean age of 9.65 years (3.6–15.2 years). Of these patients 13 sustained a both bone lower leg fracture, whereas seven sustained a tibial fracture. Five of these fractures were open fractures (four both bone fractures, one tibial fracture). We treated nine patients with external fixation, four patients with a Kirschner wire osteosynthesis, three patients with closed reduction alone, two patients with intramedullary nails and one patient, respectively, with plate osteosynthesis and screw osteosynthesis. No patient had significant soft-tissue injury, that is, from a run-over trauma. Five of the 20 patients had to be excluded for the fractured side due to the development of ACS. Two patients with clinical suspicion of an ACS had an immediate fasciotomy and in three further patients clinical suspicion of an ACS led to fasciotomy after closed reduction. Their data for the fractured side was excluded, yet included for the healthy side (Table 1).

On the healthy side we measured a mean compartment pressure of 15.15 mmHg (range 7–30 mmHg) in the anterior compartment (AC), 14.32 mmHg (range 8–24 mmHg) in the superficial posterior compartment (SPC) and 13.00 mmHg (range 4–21 mmHg) in the deep posterior compartment (DPC) (Table 2). The mean pressure for the AC was significantly higher than the mean pressure for the DPC (p value 0.031), however, not for the SPC (p value 0.572). No significant correlation of compartment pressures and age was found for the healthy leg in any compartment (Fig. 2).

The mean compartment pressure measurements were as expected higher for all 3 measured compartments on the fractured side compared to the healthy side (Table 2). This was, however, only statistically significant for the AC (Wilcoxon-Test; p value 0.021). On the fractured side the highest mean pressure was measured in the AC with 24.07 mmHg (range 5–40 mmHg). This was followed by the SPC with 17.21 mmHg (range 7–29 mmHg) and then the DPC with a slightly lower value of 17.13 mmHg (range 6–37 mmHg).

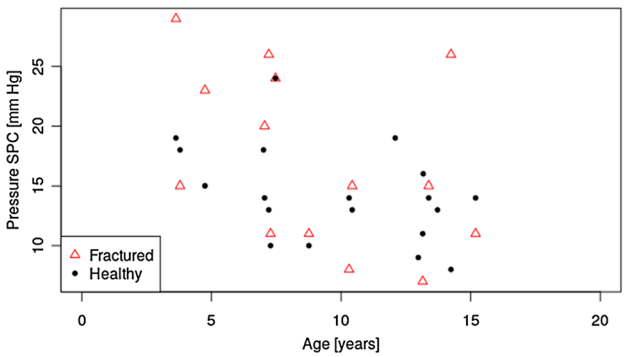

Fig. 2 No significant correlation between pressure and age on the healthy leg in the superficial posterior compartment. *SPC* superficial posterior compartment

Table 2 Mean values, standard deviation, minimal and maximal pressures (mmHg) within the studied compartments

	Age	Healthy AC	Fractured AC	Healthy SPC	Fractured SPC	Healthy DPC	Fractured DPC
Mean	9.65	15.15	24.07	14.32	17.21	13.0	17.13
SD	3.66	5.70	10.53	4.01	7.34	4.1	9.54
Min	3.63	7.00	5.00	8.00	7.00	4.0	6.00
Max	15.19	30.00	40.00	24.00	29.00	21.0	37.00

SD standard deviation, *min* minimum, *max* maximum, *AC* anterior compartment, *SPC* superficial posterior compartment, *DPC* deep posterior compartment

The mean for the AC was significantly higher than the means for the posterior compartments for fractured legs (p value 0.011 for DPC, p value 0.006 for SPC).

The pressure values amongst the compartments on the fractured side correlate significantly, however, with a wide 95% prediction interval (Fig. 3). Six of our patients had an absolute compartment pressure measurement of over 30 mmHg, all of which were on the fractured side (five in the AC, one in the DPC). Seven patients had higher absolute pressure values in at least one compartment on the healthy side compared to the corresponding compartment of the fractured leg. We calculated the perfusion gradient (Δp), the difference between diastolic blood pressure and the compartment pressure, for all values. We found a perfusion gradient < 30 mmHg in at least one compartment of the fractured leg in 13 of 15 patients, whereas in 13 of 20 patients this was also true for the healthy leg.

None of the patients with an absolute pressure value > 30 mmHg, nor those with a perfusion gradient < 30 mmHg needed fasciotomy.

All patients were seen in our outpatient clinic and were examined 3 months postoperatively. Four patients were lost for structured telephone follow-up. It was performed on average 4 years postoperatively (mean 49 months; range 11–83 months). No major complications were noted. No patient reported to have problems related to the measurement sites.

Discussion

To our knowledge this is the first study to compare normal compartment pressure measurements in non-injured and in fractured lower legs without clinical suspicion of ACS in children.

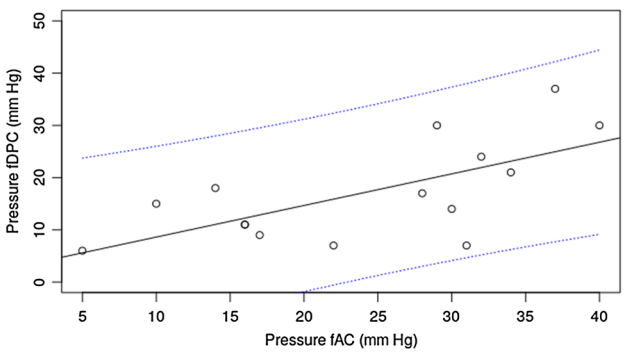

Fig. 3 Significant correlation between the deep posterior compartment and the anterior compartment on the fractured side (p value 0.006). The dotted lines show the wide 95% prediction interval. *fDPC* fractured deep posterior compartment, *fAC* fractured anterior compartment

As of yet only two publications have studied normal compartment pressure values in children. Tharakan et al. compared the compartment pressures of fractured and healthy forearms in 41 children. They found the mean pressures of the healthy forearms to be slightly higher than those of adults [9]. Staudt el al compared the compartment pressures of healthy lower legs in 20 children to those of 20 healthy adults. They, too, found higher mean values compared to adult pressure measurements [8]. Our study supports these findings showing the mean compartment pressures in the non-fractured lower legs to be between 13 and 15.15 mmHg in children. These values are considerably higher than previously published values for adult compartment pressure measurements which are between 5 and 9 mmHg [8, 13].

Further we found higher pressure values in the anterior compartment compared to all the other compartments within the healthy and fractured leg. This was statistically significant for all healthy and fractured compartments, except for the healthy AC compared to the healthy SPC. The higher pressure in the AC compared to the other compartments has previously been shown in non-injured adults, as well as in children [8, 13].

Our compartment pressure values on the fractured leg correlate significantly with each other raising the question if the measurement of only one compartment would be enough in a clinical setting. However, due to the wide 95% prediction interval of the compartment pressure values, one measurement is not sufficient to exclude the diagnosis of ACS.

It is widely accepted that the indication for fasciotomy in adults is given for absolute compartment pressures of > 30–45 mm Hg or a perfusion gradient Δp of < 10–30 mm Hg [5–7, 14, 15]. It has been shown that blood flow in microcirculation ceases when the tissue pressure in a compartment equals the diastolic blood pressure. Tissue perfusion significantly decreases with compartment pressures of 20 mm Hg below diastolic blood pressure. Compartment pressures within 10–30 mm Hg of the diastolic blood pressure have, therefore, been suggested as a threshold for surgical fasciotomy [5, 14–16]. We anticipated that children can tolerate a smaller perfusion gradient than adults due to their higher normal compartment pressure values and lower normal blood pressure values. This could be confirmed within our study setting as we found 13 fractured legs and 13 healthy legs to have a perfusion gradient < 30 mmHg without clinical signs of ACS. Therefore, using an absolute pressure value > 30 mmHg or a perfusion gradient < 30 mmHg as in adult patients as a cut-off for fasciotomy would likely lead to unnecessary procedures in the pediatric population.

Due to the differences in pressures between children and adults it would seem plausible that the higher pediatric baseline compartment pressures gradually decrease to normal adult values with increasing age. This, however, could not

be shown by either of the previously mentioned studies nor by our own.

The limitations of this study are certainly its small patient number, especially of the fractured lower legs due to having to exclude 5 patients with ACS. Further, within this study setting we performed pressure measurements at a standardized localisation. Literature has, however, shown compartment pressures to be highest within 5 cm of the fracture making it possible that some of our measured values are falsely low compared to reality [17]. Additionally, due to reluctance of our local Ethics Committee to allow measurements of the lateral compartment due to risk of injury of the peroneal nerve we performed measurements in only three of the four compartments of the lower leg.

As discussed above the clinical diagnosis of ACS is difficult in children and our study showed further that neither the absolute value nor the perfusion gradient for intracompartmental pressures are good objective parameters to diagnose ACS. Other diagnostic tools for ACS have been discussed. Just recently near-infrared spectroscopy (NIRS) has been evaluated in adults as a continuous, non-invasive monitor for ACS [18]. It may be an ideal screening or monitoring system for ACS in the pediatric population. NIRS is tissue oximetry in real-time, continual and responsive. However, more studies are necessary before this tool can be safely used in an everyday clinical setting.

In conclusion we could show that children have higher normal compartment pressures than adults in the lower leg. They seem to be able to tolerate higher absolute compartment pressures and lower pressure gradients before ACS occurs. But in light of the scarce data we have, we would recommend to respect the accepted threshold values in adults.

No technology has replaced clinical judgement in the diagnosis of ACS yet.

Absolute compartment pressures alone are not decisive—it must always be considered in the clinical context. Therefore, due to the high morbidity of a missed compartment syndrome, the old surgeon's maxim is still valid: if in doubt, do a fasciotomy.

Funding The authors hereby confirm that no funding was received for this project.

Compliance with ethical standards

Conflict of interest The authors hereby confirm that no conflicts of interest exist.

Ethical approval The project was approved by our local Ethics Committee.

References

1. Seddon HJ. Volkmann's contracture: treatment by excision of the infarct. J Bone Joint Surg Br. 1956;38-B(1):152–74.
2. Volkmann RV. The Classic: ischaemic muscle paralyses and contractures. Clin Orthop Relat Res. 2007;456:20–1. https://doi.org/10.1097/BLO.0b013e318032561f.
3. Bae DS, Kadiyala RK, Waters PM. Acute compartment syndrome in children: contemporary diagnosis, treatment, and outcome. J Pediatr Orthop. 2001;21(5):680–8.
4. Broom A, Schur MD, Arkader A, et al. Compartment syndrome in infants and toddlers. J Child Orthop. 2016;10(5):453–60. https://doi.org/10.1007/s11832-016-0766-0.
5. Whitesides TE, Haney TC, Morimoto K, et al. Tissue pressure measurements as a determinant for the need of fasciotomy. Clin Orthop Relat Res. 1975;113:43–51.
6. Matsen FAF, Winquist RAR, Krugmire RBR. Diagnosis and management of compartmental syndromes. J Bone Joint Surg Am. 1980;62(2):286–91.
7. Cohen MS, Garfin SR, Hargens AR, et al. Acute compartment syndrome. Effect of dermotomy on fascial decompression in the leg. J Bone Joint Surg Br. 1991;73(2):287–90.
8. Staudt JM, Smeulders MJC, van der Horst CMAM. Normal compartment pressures of the lower leg in children. J Bone Joint Surg Br. 2008;90(2):215–9. https://doi.org/10.1302/0301-620X.90B2.19678.
9. Tharakan SJ, Subotic U, Kalisch M, et al. Compartment pressures in children with normal and fractured forearms: a preliminary report. J Pediatr Orthop. https://doi.org/10.1097/BPO.0000000000000471.
10. Hargens AR, Ballard RE. Basic principles for measurement of intramuscular pressure. Oper Tech Sports Med. 1995;3(4):237–42.
11. Boody AR. Accuracy in the measurement of compartment pressures: a comparison of three commonly used devices. J Bone Joint Surg Am. 2005;87(11):2415. https://doi.org/10.2106/JBJS.D.02826.
12. Van Buuren S. Flexible imputation of missing data. CRC Press, Boca Raton, 2012.
13. Gershuni DH, Yaru NC, Hargens AR, et al. Ankle and knee position as a factor modifying intracompartmental pressure in the human leg. J Bone Joint Surg Am. 1984;66(9):1415–20.
14. Whitesides T, Heckman M. Acute compartment syndrome: update on diagnosis and treatment. J Am Acad Orthop Surg. 1996;4(4):209–18.
15. Matava MJ, Whitesides TE, Seiler JG, et al. Determination of the compartment pressure threshold of muscle ischemia in a canine model. J Trauma Injury Infect Crit Care. 1994;37(1):50–8.
16. Dahn I, Lassen NA, Westling H. Blood flow in human muscles during external pressure or venous stasis. Clin Sci. 1967;32(3):467–73.
17. Heckman MM, Whitesides TE, Grewe SR, et al. Compartment pressure in association with closed tibial fractures. The relationship between tissue pressure, compartment, and the distance from the site of the fracture. J Bone Joint Surg Am. 1994;76(9):1285–92.
18. Shuler MS, Roskosky M, Kinsey T, et al, 2018. Continual near-infrared spectroscopy monitoring in the injured lower limb and acute compartment syndrome: an FDA-IDE trial. Bone Joint J. https://doi.org/10.1302/0301-620X.100B6.