Normal compartment pressures of the lower leg in children

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Compartment pressures have not previously been studied in healthy children. We compared the pressures in the four lower leg compartments of healthy children with those of healthy adults.

We included patients aged between two months and six years, and measured the pressures in 80 compartments of 20 healthy children using simple needle manometry. Measurements were repeated in a control group of 20 healthy adults.

The mean compartment pressure in the lower leg in children was significantly higher than in adults ($p < 0.001$). On average, pressures in the four compartments varied between 13.3 mmHg and 16.6 mmHg in the children and between 5.2 mmHg and 9.7 mmHg in the adults. The latter is in accordance with those recorded in the literature. The mean arterial pressure did not relate to age or to pressure in the compartment.

The findings of this study that the normal compartment pressure of the lower leg in healthy children is significantly higher than that in adults may be of considerable significance in clinical decision-making in children of this age.

Compartment pressure can reach a critical level and jeopardise perfusion of limbs. Myonecrosis can cause rhabdomyolysis and myoglobinaemia, leading to organ damage and possible limb amputation. Fasciotomy should be performed to prevent such complications. Common causes of acute compartment syndrome are fractures, ischaemia-reperfusion injury, haemorrhage, intravenous/intra-arterial drug injection, prolonged limb compression, crush injury, burns, and septic conditions such as meningococcal sepsis.

Compartment pressures can be measured by several techniques. Whitesides et al,¹ in 1975, introduced needle manometry. Since then, various other methods have been developed, such as the Wick catheter, the slit catheter, the solid-state transducer intra-compartment catheter, the myopress catheter, the Stryker device and the transducer-tipped fibre-optic catheter.²⁻⁷ However, simple needle manometry may be considered the best method. It is used most often because it is the easiest and cheapest way of measuring compartment pressure, and has proved to be at least as accurate as other methods.^{8,9}

Several authors have investigated the compartment pressure at which a fasciotomy should be indicated.¹⁰⁻¹⁸ However, only a few studies¹⁹⁻²² used a standardised method of

measurement. These showed the normal compartment pressure in the lower leg in adults to be between 0 mmHg and 10 mmHg.¹⁹⁻²²

Recommendations for fasciotomy have been based on measurements of compartment pressure in the lower leg of trauma patients in some studies.^{10,23} Fasciotomy should be performed when the difference between the compartment pressure and the diastolic blood pressure (ΔP) is less than 30 mmHg (ΔP = compartment pressure-diastolic blood pressure) according to one study.¹⁸ Others prefer to use the mean arterial pressure (MAP) instead of the diastolic pressure to determine the ΔP .²³ These values of compartment pressure, and recommendations for fasciotomy, are widely used for clinical decision-making in adult patients, as well as in adolescents and children.²³

Based on our clinical experience in children with compartment syndrome caused by meningococcal sepsis, we noticed that children can have a $\Delta P < 30$ mmHg without clinical signs of tissue damage. In these septic episodes, diastolic blood pressure and MAP often fall below 40 mmHg, so that a fasciotomy might be performed in non-critical legs if the international recommendations for treating compartment syndrome are followed.

Compartment pressures have not previously been studied in healthy children. Therefore, to

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Fig. 1

Photograph showing measurement of compartment pressure in the lower leg. Note the support under the lateral malleolus and head of fibula to avoid external pressure on the compartments.

test whether normal compartment pressures in children are indeed higher than in adults, we measured them in the lower leg of healthy children using simple needle manometry.

Patients and Methods

We included 20 healthy children in the study. There were ten boys and ten girls with a mean age of 2 years 2 months (2 months to 81 months) who underwent elective plastic surgery on the hands and head. Approval was given by the Medical Ethics Committee and informed consent was given by the parents. Children who had recently suffered trauma to the legs, had an intramuscular injection, or who had metabolic pathology or septic episodes were excluded.

A control group of 20 adults (ten men and ten women) with a mean age of 40.5 years (19 to 66) who underwent elective plastic surgery were included in the study, using the same criteria.

Measurements of the compartment pressure in the lower leg were taken at the end of the operation while the patients were under general anaesthesia. Because the measurements were at the end of the operation, the effects of previously administered muscle relaxants were taken into account.

Compartment pressure measurement. Measurements of all four compartments of the leg (anterior, lateral, superficial posterior and deep posterior) were made using a standardised method of simple needle manometry as previously described.^{1,8} All patients were supine with the legs in the resting position,^{19,22} the foot in slight plantar flexion and the lateral malleolus and head of the fibula slightly elevated to avoid pressure on the calf (Fig. 1). Before insertion of the needle, the system was calibrated. A single-ported 21G needle⁸ was positioned on a pressure monitoring kit (Baxter, Irvine, California) and monitored via an arterial

pressure line (Baxter) in both the adults and the children. Pressures in all four compartments were measured consecutively in random order. The needles were inserted in a circular fashion around the thickest part of the gastrocnemius muscle in the proximal third of the lower leg. After insertion of the needle, the system was flushed with 0.2 ml of 0.45% NaCl. Care was taken that no air was trapped in the system. After one minute the compartment and blood pressures were measured.⁸ The blood pressure was measured by using a cuff and the MAP calculated. We used the MAP because we wanted to include the diastolic and the systolic blood pressure, as they are both responsible for tissue perfusion.

Statistical analysis. A general linear model for repeated measures was used to test the statistical significance of the differences found. Within-subject factor was the pressure of the four separate compartments; between-subject factor was the grouping in either the adult or the child group. The MAP was included in the model as a covariate. A p -value < 0.05 was considered to be significant.

Results

There was a significant difference in the compartment pressures in the children compared with the adults ($p < 0.001$; Table I). By contrast, the compartment pressures did not significantly differ between themselves ($p = 0.566$), although there was a tendency for the anterior compartment to be the highest in both groups (Fig. 2). The mean MAP in adults was 69 mmHg (SD 12) and in children was 64 mmHg (SD 10). The MAP did not differ significantly ($p = 0.099$), and did not contribute significantly to the variation in compartment pressure.

In the children, compartment pressures were not related to age ($R^2 = 0.0125$; Fig. 3) or weight ($R^2 < 0.005$).

Table I. Mean compartment pressures (mmHg) for 20 children and 20 adults, including standard deviation and correlation

	Compartment			
	Anterior	Lateral	Deep posterior	Superficial posterior
Adult	9.7 (4.8)	6.0 (3.1)	5.15 (2.4)	5.7 (2.2)
Children	16.6 (6.7)	14.3 (4.8)	13.4 (4.9)	14.1 (4.3)

Fig. 2

Graph showing the mean compartment pressures in adults and children, for all four compartments. Note the tendency for the anterior compartment pressure to be higher both in adults and children. This was not significant.

Fig. 3

Scatterplot of the compartment pressure (CP) of the anterior compartment in children aged between 2 and 81 months, including a regression line of best fit. No relationship exists between age and compartment pressure within this group. Scatterplots of the other compartments showed a similar trend.

Discussion

This study shows that the compartment pressures in the lower leg of healthy children are significantly higher than those of adults. We believe this is the first study to report the normal value of compartment pressures in young children. The normal value for adults has previously been described as between 0 mmHg and 10 mmHg.¹⁹⁻²² However, this study showed eight adult patients (40%) to have pressures just above 10 mmHg, and one a pressure of 27 mmHg in the anterior compartment with no clinical evidence of a chronic compartment syndrome. Previous studies have shown that resting pressures in chronic compartment syndrome can be as high as this without symptoms at rest.^{24,25}

We used a method of measurement based on the recommendations of Gershuni et al¹⁹ and Weiner et al,²² but made a few adjustments to standardise our procedure in order to make it applicable in experimental and clinical settings. First, we chose small-diameter needles (21G) to minimise tissue

damage. Mars et al⁸ compared needles of various diameters with the so-called 'gold standard' 18G double-ported needle and concluded that the use of smaller-diameter needles is equally reliable. Recently, Boody and Wongworawat⁹ compared three commonly-used devices for compartment pressure measurement and compared needles of different lengths and port configuration, ranging from 18G to 25G, against the 18G, long, double-ported needle. They confirmed that simple needle manometry is the most reliable method for accurate measurement of compartment pressure. An 18G single-ported needle overestimated the pressure, as has been confirmed by others.^{8,26,27} All compartments in the adults and the children were measured with a 21G needle. The results from the present study show that needle manometry can be performed using small needles, and that the addition of a side-port is unnecessary in needles of small volume. We measured the compartment pressure under general anaesthesia, whereas others have measured it under local anaesthesia.¹⁹⁻²² We therefore included the adult group to validate our results and exclude bias as a result of this modification of the

method of measurement. The results in the adults were similar to those described previously, although the pressures in adults were high they were still within the normal range of some previous studies.¹⁹⁻²² This may represent an effect of general anaesthesia or the physiological state of the patient during surgery. It may be argued that anaesthesia or the position of the patient may have a more potent effect in children.

We assumed that the pressure within a compartment was constant, and so slight differences in the placement of the needle would not affect the measurement. Theoretically, the wrong compartment may have been chosen, as the needle was inserted based on palpation. However, all measurements were done by the same investigator (JMS) who had considerable experience with measuring compartment pressure and sufficient knowledge of the anatomy of the lower leg. Because simple needle manometry requires the system to be flushed with 0.2 ml of fluid, a positive pressure is induced in the intramuscular space. This may cause an artificially high pressure measurement if measured directly after flushing. However, it has been shown that after one minute the 0.2 ml 0.45% NaCl has dissolved in the surrounding tissue.⁸ No further infusion of saline was used after flushing once, and an accurate measurement could be taken one minute after flushing. We therefore conclude that our methodology did not invalidate the results.

It is difficult to explain the high normal pressures in children compared with those of adults. On clinical examination, we noticed that the tightness of the calves in elderly inactive patients was less than that of the children and active adults. Children are in a stage of muscle growth, and the increasing volume due to muscle hypertrophy may press against the surrounding fascia. Chronic compartment syndrome in some athletes is thought to be caused by muscle hypertrophy.²⁸ There may be a similar situation in children, although none of the children whose compartment pressures were measured had any symptoms of compartment syndrome.

Although there were no symptoms, the recommendations suggested by McQueen and Court-Brown¹⁸ indicate that tissue perfusion may be threatened when the diastolic pressure is > 30 mmHg. The high pressures measured in the absence of a concomitant increased MAP in our children could imply a potential threat to the perfusion of the tissues in the lower leg.^{10,23} We may question whether these recommendations have to be changed for children; however, the recommendations suggested by McQueen and Court-Brown¹⁸ were for unhealthy legs. Measurements and clinical findings in healthy patients cannot be simply extrapolated to unhealthy children. It is not clear whether the finding of a higher baseline pressure in children means that they can tolerate lower differences between compartment pressure and MAP, or whether children may reach a critical pressure difference more easily than adults because only a small increase in compartment pressure is required to create a compartment syndrome. Our findings merit further study of how

tissue perfusion in the leg differs between children and adults, and whether different guidelines for fasciotomy in children should be considered. Obviously, the indication for fasciotomy is not based solely on increased compartment pressure. The clinical presentation is the most important indication. Ideally, tissue oxygenation or ischaemia within the compartments should be measured. However, no clinically applicable standardised measurements of tissue oxygenation are available as yet. Compartment pressure is considered a useful tool in decision-making and patient monitoring, particularly in intensive care patients in a similar state of sedation. The present study shows that the indication for fasciotomy in young patients at a diastolic pressure of 30 mmHg may have to be adjusted to take into account the higher normal compartment pressure in children.

A single measurement in one of the four compartments seems to adequately estimate pressures in the compartments of the lower leg in healthy children and adults, as none of them differed significantly within subjects. However, there is a tendency for the pressure in the anterior compartment to be higher than in the others. A larger sample size may answer the significance of this tendency.

This study shows that the pressures in the compartments of the lower leg in healthy children are significantly higher than those in healthy adults. The estimates of normal compartment pressures available in the literature for adults may not be valid for young children between the ages of two months and six years. A single measurement in one of the four compartments seems to estimate the pressures in the compartments of the lower leg adequately in both healthy children and adults.

Supplementary Material

A table showing the compartment pressures of the individual children is available with the electronic version of this article on our website at www.jbjs.org.uk

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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