The Pink Pulseless Hand: A Review of the Literature Regarding Management of Vascular Complications of Supracondylar Humeral Fractures in Children

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Abstract
Supracondylar fractures of the humerus are the commonest upper limb fractures in children, accounting for up to 70% of all paediatric elbow fractures [Wilson MJ, Hunter JB. Supracondylar fractures of the humerus in children—wire removal in the outpatient setting. Injury Extra 2006 Aug;37(8):313–315] and are often complicated by neurovascular injury. Much confusion surrounds the management of the child with a "pink pulseless hand" post-fracture reduction and several treatment options have been proposed including observation, immediate exploration and angiography. The literature contains a number of case series with variable follow-up. Both angiography and colour duplex ultrasound provide little benefit in the management of these patients. A child with a pink pulseless hand post-fracture reduction can be managed expectantly unless additional signs of vascular compromise develop, in which case exploration should be undertaken.

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Introduction
Supracondylar fractures of the humerus are the commonest upper limb fractures in children, accounting for up to 70% of all paediatric elbow fractures1 because of the relative strength of surrounding ligaments in comparison to bone. Due to the close proximity of nerves and vascular structures to the elbow joint, these fractures are often complicated by neurovascular injury. The incidence of vascular complications presenting as an absent or diminished pulse (usually defined as non-palpable but detected by duplex ultrasound) has been reported as between 3.2% and 14.3%2–10 with ischaemia, amputation and Volkmann’s contracture being the most serious potential end-points of vascular injury.11,12 Despite the frequency of these injuries the management of these fractures has long been debated by vascular and orthopaedic surgeons especially with regards to the indications for exploration of the brachial artery in a clinically well-perfused hand.
This review seeks to address the confusion surrounding the management of the child who displays a persistently absent pulse with a pink, warm hand, in spite of satisfactory first line treatment, deemed by most authors to be closed reduction and percutaneous fixation. We hope to clarify the role of angiography in these cases and discuss the use of newer techniques for vascular assessment including pressure monitoring and duplex scanning.

**Materials and methods**

Medline and PubMed databases were searched using combinations of the search terms “supracondylar fractures”, “humeral fractures”, “vascular injury”, “vascular complication”, “vascular compromise” and “pulse”. Relevant articles published from 1980 onwards, written in English, and relating to children were obtained. The references of each article were also searched to identify other relevant papers. No Cochrane review articles or randomised controlled trials of management of supracondylar fracture vascular injuries were identified. The 73 articles that were obtained for the initial search were assessed for relevance by the authors. Many were found to relate to the initial management of supracondylar fractures (i.e. closed reduction, pinning and the use of traction) and not to the associated vascular injuries. These reports were not utilised in this review. Those papers published prior to 1980 were also discarded, although reference to the historical management of these injuries has been included.

**Results**

**Incidence**

The incidence of vascular compromise associated with supracondylar fractures has been reported as ranging from 3.2% to 14.3% in population study groups that range from 128 to 840 in number. The ages of these study groups, where reported, range from 1 to 15 years. The available series all comprised children who had sustained displaced extension-type supracondylar fractures (Grade III as classified by Gartland and modified by Wilkins). The literature has consistently shown that it is these fractures that are associated with brachial artery injury with flexion-type supracondylar fractures being relatively free of vascular complications. Copley et al. found that there was an increased likelihood of vascular complications in injuries sustained via “high energy trauma” (fall >4 feet, fall down >4 stairs, motor vehicle accidents and athletic injuries). In the series by Garbuz et al., those children who presented with an absent radial pulse had a 60% incidence of associated neurological injury. In only one series was a distinction made on assessment of vascular status between an “absent” pulse (clinically impalpable and not present on Doppler scanning) and a diminished pulse (present on Doppler but impalpable). Of the 17 children in this series a pulse was absent in eight patients and diminished in nine, although no further discussion was made as to which of these patients progressed to open vascular exploration and which demonstrated return of pulse after closed reduction alone.

**Initial management**

The immediate management of supracondylar fractures has been discussed at length in the literature and although there is still controversy, most authors would advocate a closed reduction and percutaneous pinning (for stabilisation) protocol for closed supracondylar fractures of the humerus, as first described by Swensson. Hadlow et al. suggest a more dynamic approach to initial management and point out that such an “oversimplified” approach to stabilisation will result in unnecessary pinning of stable fractures when casting could achieve an equal or superior result. All the series obtained used reduction (closed or open) as the first stage in management, combined with casting, K-wire stabilisation or traction. Only when the pulse was persistently absent (with good perfusion) following this reduction was the patient considered for further procedures ± exploration.

In the majority of cases this initial management was sufficient to bring about the return of the previously absent radial pulse and in only 27.7% of cases (data combined from refs. 2–5) did absence persist; not all series comment on whether this lack of radial pulse was accompanied by poor circulatory status (i.e. white cold hand) and the length of time that determines “persistence” also varied considerably between studies. Copley et al. advocate exploration within just 30 min of a “persistently absent” pulse post-reduction whereas Sabharwal et al. described proceeding to angiography only after 8–12 h of close observation.

**Subsequent management—observation**

The most difficult aspect of managing children with supracondylar fractures, is the question of how to proceed when an apparently satisfactory attempt at closed reduction has failed to re-establish a palpable pulse. If the lack of radial pulse is associated with poor circulatory status (as shown by pallor, pain, paraesthesia, etc.) then exploration of the brachial artery is indicated. However a warm, pink, hand with clinically good perfusion is a different matter. Both Pirrone and Garbuz promote a “watch and wait” approach with careful observation and regular assessment of neurovascular status, particularly looking for signs of impending compartment syndrome. In the work by Garbuz et al., 22 patients (6.7%) initially presented with an absent radial pulse on admission. Of these, 16 had good perfusion (Group 1) and six demonstrated poor perfusion, with a cold white hand (Group 2). After initial management, seven had return of pulse after open reduction, 10 had return of pulse after closed reduction and five (22.7%) showed no pulse but good perfusion; of these, three had originally been from Group 1 (“pink”) and two had originally been from Group 2 (“white”). All five of these cases were observed for 48 h with no angiography performed; none developed vascular compromise or compartment syndrome and all had normal range of motion, carrying angle, neurovascular status and functional ability at final review. The decision not to perform angiography in these patients was based on the work of Shaw et al. who present a series of 143 cases (with 17 incidences of vascular compromise) where no arteriography was performed with no late vascular compromise or functional impairment on follow-up. The work of Pirone...
et al. had similar findings although initial management in this series included closed reduction, reduction and casting, reduction and stabilisation with K-wires, and reduction with traction. In four cases the radial pulse did not return and these children (who had no other signs of ischaemia) were similarly observed in hospital. No permanent sequelae were recorded at final follow-up (mean time 4.6 years) and the radial pulse was found to return at day 1–4 post-reduction. The authors state that arteriography would “delay definitive treatment” and make particular note that “only patient who developed a Volkmann’s contracture had a palpable pulse until just prior to fasciotomy. Hence, they, like many others in the literature emphasise that “absence of the pulse alone is not an indication for immediate vascular exploration if there are no other signs of ischaemia”. The work of Louahem et al. would “delay definitive treatment” and make particular note that the only patient who developed a Volkmann’s contracture had a palpable pulse until just prior to fasciotomy. Hence, they, like many others in the literature emphasise that “absence of the pulse alone is not an indication for immediate vascular exploration if there are no other signs of ischaemia”. The work of Louahem et al. supports this view with 26 patients (from a population of 210) presenting with a pink and pulseless hand. In 21 of these children, reduction successfully restored the radial pulse, in three others additional signs of ischaemia became apparent and exploration was performed, and in the other two cases the hand remained pulseless but with clinically good distal perfusion. These children were observed closely (with arterial oxygen saturation as the measure of perfusion) and in both cases the pulse returned within 6 days. The authors therefore conclude; “persistent absence of radial pulse, but with good distal perfusion ... justifies an expectant treatment approach”.

It is interesting that only two study groups reported on the use of compartment pressure measuring in the assessment of vascular injuries following supracondylar humerus fracture. Pirone et al. utilised this technique in only three patients, two of whom had normal pressures and one, initially treated with reduction and casting, who was found to have elevated pressures and clinical features of compartment syndrome. Copley et al. also measured compartment pressures in six cases, documenting pressures ranging from 11 to 25 mmHg. Although no explanation is made of why these six cases were chosen for measurement of compartment pressures, the one child clinically determined to have compartment syndrome did have elevated pressures (25 mmHg in the volar compartment and 24 mmHg dorsally). In comparison to many papers relating to compartment syndrome of the lower limb we have found no evidence for consideration of absolute values of upper limb compartment pressure or indeed for the usefulness of measuring the absolute values of radial pressure.

The long-term sequelae of not diagnosing vascular injuries in the paediatric population has not been fully described in the literature. Although no paper described the development of late Volkmann’s contracture it may be that occult vascular complications (i.e. those that do not give rise to acute ischaemia) have other, more subtle, consequences such as limb length discrepancy and functional impairment. All those cases with a pink pulseless hand who were observed appear to have had a good functional recovery with no objective difference between them and those cases undergoing exploration. Garbuz et al. report normal range of motion in all five of the children who were observed with a pink pulseless hand post-fracture reduction. It should be noted however, that the follow-up in all the studies referenced is variable both in terms of duration and with regards the numbers of patients “lost to follow-up”. The average length of follow-up, where quoted, was just over 3 years and 6 months (see Table 1) and this may not be long enough to fully assess all complications. However, data from an historical cohort of paediatric patients undergoing brachial artery ligation for insertion of a Scribner shunt suggests that long-term sequelae are probably minimal. Lally et al. reviewed 11 patients who underwent brachial artery ligation as children a mean of 15.8 years post-operatively, from a total experience of 27 patients. No patient developed critical limb ischaemia in the peri-operative period. Unsurprisingly, systolic blood pressures were significantly lower on the ligated side, but no patient reported significant functional impairment. Several had mild claudication on exercise testing. Given the lack of long-term functional disability following brachial artery ligation, it would seem reasonable to conclude that a missed brachial artery occlusion is unlikely to have devastating consequences, justifying the pursuit of a 0% negative exploration rate in these patients.

**Subsequent management — exploration**

Several authors have promoted early exploration of vascular injuries in children who present with a persistently absent radial pulse post-fracture reduction and historically it was felt by many that “it is the moral obligation of the surgeon to proceed ... with exploration of the antebrachial fossa without delay ... [regardless of the fact that] some surgical procedures will be performed needlessly by adopting such an attitude”. Copley et al. provide evidence to support this theory by presenting a series of 128 children with Grade III supracondylar fractures, 17 (13.2%) presented with an absent or diminished radial pulse. In 14 (82.4%) patients the pulse was restored with reduction and fracture stabilisation leaving just three (17.6%) with a persistently absent pulse. These three patients were all explored immediately (during the same anaesthesia) when the pulse failed to return within 30 min of fracture reduction. They were found to have a significant vascular injury requiring repair (release of entrapped artery, direct repair and bypass graft) and in two cases on-table angiography was used although it was not felt that this investigation provided “further information ... to help define or locate the vascular injury” again because the vascular injury was in each case anatomically related to the fracture site. In two further cases described by Copley the radial pulse initially returned following closed reduction and then subsequently became impalpable over the next 24–36 h. These patients were both taken to theatre following angiography and underwent vascular repair. Of note in these patients and in the three other cases requiring vascular exploration, the authors highlight the presence of signs of vascular insufficiency, which were noted prior to operation. These signs (along with pulselessness) are pallor, pain, paraesthesia and paralysis and in each of the five cases at least two of these signs were present pre-operatively, thus emphasising the importance of thorough vascular assessment of all supracondylar fracture patients. Copley et al. make note that the signs of ischaemia which are often considered to be “late signs”
### Table 1  Summary of recent clinical studies: The management of the pink pulseless hand

<table>
<thead>
<tr>
<th>Ref. No</th>
<th>Author</th>
<th>Year</th>
<th>Total No. of patients</th>
<th>No. of patients presenting with pulseless hand</th>
<th>No. of patients with pulseless hand after initial Mx</th>
<th>Management (in addition to reduction)</th>
<th>Average follow-up period</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Garbuz et al.</td>
<td>1996</td>
<td>326</td>
<td>22 (6.7%) (16 pink and pulseless &amp; 6 white and pulseless)</td>
<td>5 (3 from pink group and 2 from white group)</td>
<td>Observation in hospital. No angiography</td>
<td>4.5 years</td>
</tr>
<tr>
<td>3</td>
<td>Pirone et al.</td>
<td>1988</td>
<td>230</td>
<td>22 (9.6%) (21 pink and pulseless &amp; 1 white and pulseless)</td>
<td>4 (initial Mx of closed reduction/K wires/traction)</td>
<td>Observation in hospital. No angiography</td>
<td>4.6 years</td>
</tr>
<tr>
<td>4</td>
<td>Copley et al.</td>
<td>1996</td>
<td>128</td>
<td>17 (13.3%) absent/diminished</td>
<td>3 (initial Mx of closed reduction and pinning)</td>
<td>Immediate exploration; all 3 found to have sig vascular injuries. Angiography used in 4 cases, not felt to have altered course of Mx</td>
<td>28 months</td>
</tr>
<tr>
<td>5</td>
<td>Sabharwal et al.</td>
<td>1997</td>
<td>410</td>
<td>13 (3.2%) (all pink and pulseless, 12 closed and 1 open fracture)</td>
<td>12 (initial Mx of closed reduction and pinning)</td>
<td>Observed for 8–12 h, then angio ± urokinase or exploration</td>
<td>31 months</td>
</tr>
<tr>
<td>15</td>
<td>Luria et al.</td>
<td>2007</td>
<td>519</td>
<td>24 (4.6% absent/diminished pulse (4 had signs of ischaemia)</td>
<td>11 (initial Mx of closed reduction, 1 had conservative Mx, 1 had open fracture)</td>
<td>11 explored (7intimal tears, 2 spasm, 1 entrapment), 6 had angio (5 intimal tears, 1 spasm), Intra-op angio should be used in all cases where pulse does not return</td>
<td>7 years &amp; 3 months</td>
</tr>
<tr>
<td>14</td>
<td>Rabee et al.</td>
<td>2001</td>
<td>86</td>
<td>Not documented</td>
<td>6 (initial Mx closed reduction and pinning; 5 pink and pulseless, 1 white and pulseless)</td>
<td>Exploration of brachial artery; 5 found to have entrapment of artery at fracture site, 1 had compartment syndrome</td>
<td>Not documented</td>
</tr>
<tr>
<td>6</td>
<td>Noaman et al.</td>
<td>2006</td>
<td>840</td>
<td>120 (14.3%)</td>
<td>31 (initial Mx of closed reduction and pinning)</td>
<td>All 31 explored (17 aneurysm and thrombus, 8 complete injury, 3 thrombosis, 2 partial tear, 1 entrapment)</td>
<td>26 months</td>
</tr>
<tr>
<td>7</td>
<td>Louahem et al.</td>
<td>2006</td>
<td>210</td>
<td>29 (13.8%); 26 pink and pulseless, 3 white and pulseless</td>
<td>5 pulseless (initial Mx of reduction); 2 pink, 3 white</td>
<td>Expectant Mx of pink pulseless and hand: both returned at 4–6/7</td>
<td>Not documented</td>
</tr>
<tr>
<td>13</td>
<td>Shaw et al.</td>
<td>1990</td>
<td>143</td>
<td>17 (11.9%)</td>
<td>2 (initial Mx of closed reduction and K wires; 1 pulseless with decreased cap refill, 1 white, 1 pulseless but Doppler present</td>
<td>2 explored (1 intimal tear, 1 entrapment), and 1 observed</td>
<td>17 months</td>
</tr>
</tbody>
</table>
were actually present within 6 h of injury and thus may be used as indicators of the need for surgical intervention when a “watchful waiting” strategy is employed. Other authors also provide evidence to support the theory that early exploration yield injuries which are susceptible to vascular repair; Rabee et al.\textsuperscript{9} described six cases of a pink pulseless hand post-reduction (from a series of 86) where exploration revealed brachial artery entrapment, Noaman et al.\textsuperscript{6} in 2006 explored all 31 cases where the radial pulse failed to return post-reduction and discovered injuries including aneurysms (17), complete vascular injury (8), thrombosis (3), partial tears (2) and entrapment (1), and Shaw et al.\textsuperscript{6} also report three vascular injuries (two intimal tears and one entrapment) discovered at the time of exploration. Noaman et al. performed “no negative exploration”\textsuperscript{6} in their series, the presumed ideal because of the not-insignificant risks of surgery, and stated that “spasm, kinking or impaled brachial artery should be improved by reduction”.\textsuperscript{6} This has not been replicated in all studies however, and Luria et al.\textsuperscript{10} report two cases (from 11 explored) of arterial spasm resulting in pulselessness post-reduction. There is no question therefore, that injuries requiring operative management are present in some cases but whether or not all these injuries need operative management or whether collateral circulation is sufficient to allow adequate perfusion (in the absence of a clinically palpable pulse) has not yet been proven. It should be noted that surgical exploration is not without its downsides, exposing the child to a general anaesthetic and associated peri-operative morbidity and to the risks of infection and damage to nearby structures. Moreover, the target vessels are often several millimetres in diameter, rendering surgical reconstruction challenging. Noaman et al. make note of the introduction of a scar\textsuperscript{6} which although usually cosmetically acceptable may be unsightly and Luria et al. report a case of osteomyelitis of the distal humerus likely to reflect a late complication of surgical treatment.\textsuperscript{10} The incidence of re-operation or “2nd-look procedure” is increased when heparin or low-molecular weight anticoagulants are used after surgery and Noaman et al. report that use of these agents can lead to Volkman’s contracture due to bleeding from the suture site and surrounding tissues.\textsuperscript{5} No evidence was found in the literature for the use of other medical therapies such as vasodilators or anti-platelet medications.

Subsequent management — vascular assessment techniques

Although many studies have concluded that angiography is an unnecessary and in some cases detrimental (due to the delay it imposes, the risk of arterial damage at catheter insertion and the potential for allergic reaction to contrast material\textsuperscript{13}) investigation in the management of supracondylar fractures.\textsuperscript{3,4,8} Where angiography was utilised it allowed for the use of medical thrombolysis treatment, obviating the need for surgery. Sabharwal et al. gave urokinase thrombolysis in the treatment of three cases of brachial artery thrombus although report that in two of the three cases, subsequent investigations showed evidence of residual brachial artery stenosis.\textsuperscript{5} This highlights the fact that thrombolysis does not treat any underlying intimal injury and hence there is always the possibility of re-thrombosis. These agents obviously have other cautions such as the risk of haemorrhage and allergic reaction. The literature is less clear on the role of less invasive methods of vascular assessment. Many of the studies reviewed used duplex ultrasound to confirm the vascular status of the fractured limb (as assessed clinically) and Rabee et al.\textsuperscript{9} used Doppler in addition to a spectrum analyser to justify the exploration of six patients (all of whom had monophasic or minimal flow signals on imaging). The work of Sabharwal et al.\textsuperscript{5} used segmental pressure monitoring, colour flow duplex imaging and magnetic resonance angiography (MRA) in combination to assess the “patency of the brachial artery and collateral circulation across the elbow” and although limited by a small population size they provide evidence to suggest that these assessment methods are complementary and correlate well with traditional angiography. Sabharwal uses these non-invasive methods at follow-up to assess the clinical outcome of patients who have undergone various procedures (including exploration and vascular repair) to establish brachial artery patency. If these assessment techniques truly are comparable with angiography, they could potentially be used to assess collateral circulation and brachial artery patency, in conjunction with close observation prior to operative intervention. In theory this could prevent unnecessary operations (and invasive investigation) in those children who show good “forearm flow” as did those cases in Sabharwal’s series with “associated or isolated intimal damage” where “collateral circulation would have been adequate to maintain a viable extremity”. It is important to realise that these techniques have their limitations and duplex scanning may fail to pick up brachial artery occlusions when used in isolation. Sabharwal et al.\textsuperscript{5} hypothesise that technical error may lead to (enlarged) collateral vessels being identified as the brachial artery, thus missing stenoses and occlusions. Luria et al. report a case of the converse, where Doppler scanning mistakenly diagnosed an arterial tear resulting in unnecessary exploration of an intact vessel.\textsuperscript{10}

Conclusions

Supracondylar fractures with associated vascular injuries are a frequent cause of morbidity in the paediatric population. Angiography does not appear to be useful in this scenario, due to invasiveness, delay and the proximity of the arterial injuries to the fracture site. Colour flow duplex may prove useful in the future but requires more thorough assessment. In the meantime, management depends largely upon clinical findings. A child with a pink, pulseless hand following successful fracture reduction can be managed expectantly. However, if additional signs of ischaemia are present or develop, surgical exploration is required.

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