European Journal of Trauma and Emergency Surgery
https://doi.org/10.1007/s00068-021-01794-x

ORIGINAL ARTICLE

# Strategy of pulseless pink supracondylar humerus fracture treatment in children: a comparison of two approaches

**Radek Štichhauer**[1] · **Jindřich Preis**[1] · **Ladislav Plánka**[2] · **Jakub Turek**[2] · **Jiří Urban**[3] · **Zbyněk Horák**[4] · **Jaroslav Zeman**[5] · **Martin Konečný**[6] · **Ivo Kopáček**[7] · **Filip Hanák**[8] · **Jiří Vojta**[9] · **Veronika Chrenková**[10]

Received: 12 April 2021 / Accepted: 17 September 2021


## Abstract

**Purpose** The appropriate treatment of pulseless pink supracondylar humerus fractures (SCHF) remains controversial. In this study, the outcomes of two treatment approaches (with and without vascular surgery) were compared.

**Material and methods** This was a retrospective multicenter study of patients with pulseless pink SCHFs treated in ten pediatric surgery, trauma, or orthopedics departments in the Czech and Slovak Republic between 2014 and 2018.

**Results** Of the total 3608 cases of displaced SCHF, 125 had the pulseless pink SCHF. Of those, 91% (114/125) did not undergo vascular surgery and 9% (11/125) underwent vascular surgery. The patients who did undergo vascular surgery had radial artery pulsation restored more frequently in the operating room (73% vs. 36%; $p=0.02$), within 6 h (91% vs. 45%; $p=0.004$), and within 24 h of surgery (91% vs. 57%; $p=0.05$). However, 72 h after surgery, there was no significant difference in palpable radial artery pulsation between the vascular surgery and the non-vascular surgery groups (91% vs. 74%; $p=0.24$). Additionally, no significant differences in long-term neurological (9% vs. 22%; $p=0.46$) or circulatory (9% vs. 7%; $p=0.57$) deficits were found between the two groups.

**Conclusion** While vascular surgery in patients with pulseless pink SCHFs is associated with a more prompt restoration of radial artery pulsation, no statistical significant differences in terms of the restoration of neurological deficits or the risks of long-term neurological or circulatory deficits were found between patients with and without vascular surgery.

**Keywords** Supracondylar humerus fracture · Children · Pulseless · Pink · Vascular surgery

**Abbreviations**

| | |
|---|---|
| SCHF | Supracondylar humerus fracture |
| IQR | Interquartile range |
| *n* | Number |
| h | Hour |
| K-wire | Kirschner wire |

✉ Radek Štichhauer
radek.stichhauer@fnhk.cz

1 Department of Pediatric Surgery and Trauma, University Hospital Hradec Králové, Faculty of Medicine Hradec Kralove, Charles University, Sokolska 581, 500 05 Hradec Králové, Czech Republic

2 Clinic of Pediatric Surgery, Orthopedics and Trauma, University Hospital, Faculty of Medicine, Masaryk University, Černopolní 9, 61300 Brno, Czech Republic

3 Department of Trauma Surgery, Hospital České Budějovice, B. Němcové 585/54, 37001 České Budějovice, Czech Republic

4 Department of Pediatric Surgery, Hospital Pardubice, Kyjevská 44, 53003 Pardubice, Czech Republic

5 Clinic of Orthopedics and Trauma, University Hospital Pilsen, E. Beneše 1128, 30100 Pilsen, Czech Republic

6 Department of Pediatric Surgery and Trauma, Hospital Ústí nad Labem, Sociální péče 3316 /12A, 40113 Ústí nad Labem, Czech Republic

7 Trauma Clinic, University Hospital Ostrava, 17. listopadu 1790/5, 70800 Ostrava, Czech Republic

8 Clinic of Pediatric Orthopedics and Trauma, 2nd Faculty of Medicine, Charles University in Prague and Motol University Hospital, V Úvalu 84, 15006 Prague, Czech Republic

9 Department of Pediatric Surgery and Trauma, University Hospital Bulovka, Budínova 2, 18000 Prague, Czech Republic

10 Pediatric Surgery Department, National Institute of Children´s Diseases and Faculty of Medicine, Comenius University, Limbová 1, 83340 Bratislava, Slovak Republic

Published online: 28 September 2021

## Introduction

Supracondylar humerus fractures (SCHF) are one of the most common elbow fractures in children. The incidence is 5–7% of all pediatric fractures, accounting for approximately 70% of all distal humeral fractures and 55% of all fractures in the elbow area [1, 2]. Between 97% and 99% of these fractures occur from a fall on the extended limb and, more rarely, from a direct fall on the elbow [1, 2]. Approximately 35–40% of SCHFs are non-displaced and treatment consists of immobilization in a cast for 3–4 weeks [1–3]. However, the treatment of SCHFs is difficult, and there is a high risk of permanent consequences. Therefore, SCHF treatment outcomes are indicators of the quality of care in individual pediatric and orthopedic surgery departments.

Several classifications of SCHFs (e.g. Gartland's, AO, or Havranek's classification) have been used in clinical praxis. The classification schemes are different among countries or departments [1–3]. Fractures with significant displacement, where the fragments are not in contact with each other (Gartland III, or AO 13-M3.1/IV), are often accompanied by significant swelling, bruising, and surrounding soft tissue injury, including nerve lesions and brachial artery injury [4, 5]. According to the findings of previous studies, these accompanying symptoms occur in 10–25% of Gartland III cases [4–6]. Artery injuries can occur after the pulling or compression of a blood vessel (edema, bone fragments), intima lesions or the rupture of a blood vessel with bone fragments. Injury to the brachial artery may be accompanied by a loss of pulsation in the radial artery and often with changes in temperature, skin color at the periphery of the limb, or capillary refill. Clinically, these patients can be divided into two groups: (i) pulseless pink type: the hand and fingers are warm, have a pink color, and good capillary refill; and (ii) pulseless pale type: the hand and fingers are cold and have a pale color.

Urgent fracture reduction and fixation are generally indicated for both types of pulseless SCHFs. However, vascular surgery on the brachial artery remains controversial, especially for the pink type of SCHFs. Some authors recommend a mandatory vascular surgical revision [7–10], while others recommend that this surgical revision should be performed only when pulsation of the radial artery is not restored after fracture reduction [11, 12]. Furthermore, some of them suggest a conservative approach even if the pulsation does not resume after fracture reduction [13]. Therefore, there is no consensus regarding vascular surgery for pulseless pink fractures [1, 2, 14].

The main aim of this study, therefore, was to retrospectively compare the outcomes of two treatment approaches (with and without vascular surgery) of pulseless pink type of SCHFs.

## Material and methods

A retrospective multicenter evaluation of the outcomes of patients treated for the pulseless pink SCHFs between 2014 and 2018 was carried out in ten pediatric surgery, trauma, or orthopedics departments in the Czech Republic and the Slovak Republic.

The inclusion criteria were as follows: (i) an isolated, displaced SCHF and (ii) an un-palpable pulsation of the radial artery, (iii) the age below 15 years, (iv) the complete documentation and the follow up at the same institution. Patients were excluded for the following reasons: (i) the presence of a cold and pale hand and (ii) other associated injuries of the upper extremity, (iii) pathological fractures.

For all patients, after an initial clinical and X-ray examination, close reduction of the fracture was performed under general anesthesia and subsequent stabilization using crossed K-wires from the humeral epicondyle area was performed.

The decision regarding vascular surgery was made according to the clinician's discretion. Vascular surgery, when indicated, was performed simultaneously with or subsequent to fracture reduction and stabilization. Various types of vascular surgery were performed, including open revision and vascular deliberation, thrombectomy, or replacement of a part of the brachial artery with a venous graft. In some patients, anticoagulation or vasodilatory therapy was administered. All patients were monitored clinically and healing of bone fracture by X-ray.

The patients' medical records were reviewed in each center and clinical data were extracted.

### Clinical definitions

Nerve injury was defined as a loss of sensory and motor function of a peripheral nerve in a specific area caused by pressure, stretching, or cutting.

Long-term neurological deficits were defined as a loss of sensitivity, pain, paresthesia, tingling, feeling of cold or prickling, and specific motor deficits included paralysis, weakness, muscle atrophy, and fasciculation one year after the injury.

Long-term circulatory deficits were defined as loss of pulsation, feeling of cold, claudication, growth failure, or hypotrophy of the periphery of the limb one year after the injury.

### Statistical analysis

The patients' demographic and clinical characteristics were compared using the nonparametric Mann–Whitney *U* test for continuous variables and are presented as median values (interquartile range [IQR]). Categorical variables were compared using Fisher's exact test and are presented as numbers (%). The normality of the data was tested using the Anderson–Darling test. Differences were considered significant at $p < 0.05$. All $p$ values were obtained using two-tailed tests, and all statistical analyses were performed using GraphPad Prism, version 8.1.1. for Mac OS X (GraphPad Software, San Diego, CA, USA) or the Statistical Package for Social Sciences (SPSS) version 19.0 for Mac OS X (SPSS Inc., Chicago, IL, USA).

## Results

In total, 3608 patients with displaced SCHF were included. Pulseless SCHF was observed in 3.9% (140/3608) of the patients. Among the patients with pulseless SCHF, 89% (125/140) had the pink type and the remaining 11% (15/140) had the pale type initially.

Among those with the pink type of pulseless SCHF, 91% (114/125) did not undergo any vascular surgery; their treatment was limited to reduction and K-wire stabilization of the fracture. The remaining 9% (11/125) of the patients underwent vascular surgery during treatment (4 = vascular deliberation; 4 = venous graft; 2 = thrombectomy; and 1 = surgical revision of the brachial artery only).

Demographic and clinical parameters are summarized in Table 1. There were no significant differences between the groups in terms of their basic characteristics. Additionally, no statistically significant differences between the two groups were found regarding time intervals or changes in capillary refill. Additionally, the time intervals between injury and admission and between admission and surgery were short in both cohorts.

### Restoration of radial artery pulsation and neurological deficits

Patients with the pink type of pulseless SCHFs who underwent vascular surgery more frequently experienced restoration of radial artery pulsation in the operating room, within 6 h, within 24 h after surgery than those who did not undergo vascular surgery. Within 72 h of surgery, however, no statistical difference was found between the groups in terms of palpable radial artery pulsation (Table 2).

Additionally, no statistical differences between these groups were found in terms of neurological deficits restoration within 72 h or within 1, 3, 6, or 12 months (Table 2).

### Long-term patient follow-up

For patients with the SCHF and pink pulseless hand, no statistical differences in long-term neurological or circulatory deficits were found between the vascular surgery and the non-vascular surgery group (Table 3).

## Discussion

In children, SCHFs represent an important part of all pediatric fractures and are one of the most complicated in terms of treatment, results, and consequences. Accordingly, the recommended treatment of the pink type of pulseless SCHF is still under intense debate. The main findings of this study are as follows: (1) the intervals between injury and admission and between admission and (skeletal or vascular) surgery were short and similar in both groups; (2) vascular surgery was associated with a more prompt restoration of radial artery pulsation; (3) within 72 h, no statistical differences in the restoration of radial artery pulsation was found between the groups; and (4) no differences in long-term

**Table 1** Selected demographical and clinical characteristic of the patients included in the study

| Characteristic | With vascular surgery ($n = 11$) | Without vascular surgery ($n = 114$) | $p$ value |
|---|---|---|---|
| Patients age [years, median (IQR)] | 7.6 (6.1–10.2) | 6.8 (5.6–8.0) | 0.09 |
| Side of the fracture–right [number (%)] | 2 (18%) | 37 (33%) | 0.50 |
| Sex of the patients–girl [number (%)] | 9 (82%) | 54 (47%) | 0.06 |
| Interval between injury and admission [hours, median (IQR)] | 1.8 (1.0–2.8) | 2.3 (1.2–3.2)* | 0.38 |
| Interval between admission and surgery [hours, median (IQR)] | 1.8 (0.8–2.0) | 1.9 (1.2–2.9)# | 0.16 |
| Prolonged capillary refill [number (%)] | 1 (9%) | 9 (9%)$ | 1.00 |

Continuous variables were compared using a nonparametric Mann–Whitney $U$ test. Categorical variables were compared using the Fisher's exact test. Continuous variables are presented as median (IQR) and categorical as number (%). Statistically significant results are marked in bold

*Data available for 101 patients

#Data available for 113 patients

$Data available for 99 patients

**Table 2** Selected clinical characteristic and their restoration after the surgery

| Characteristic | With vascular surgery ($n=11$) | Without vascular surgery ($n=114$) | $p$ value |
|---|---|---|---|
| Return of pulsation after reduction and stabilization of fracture [number (%)] | 5 (45%) | 57 (50%) | 1.00 |
| Nerve injury [number (%)] | 8 (73%) | 48 (42%) | 0.06 |
| Neurologic deficit [number (%)] | 7 (64%) | 48 (42%) | 0.21 |
| Return of pulsation after surgery | | | |
| In the operation room [number (%)] | 8 (73%) | 37 (36%) | **0.02** |
| Within 6 h [number (%)] | 10 (91%) | 47 (45%) | **0.004** |
| Within 24 h [number (%)] | 10 (91%) | 59 (57%) | **0.05** |
| Within 72 h [number (%)] | 10 (91%) | 77 (74%) | 0.29 |
| Restoration of neurologic deficit after surgery | | | |
| Within 72 h [number (%)] | 0 (0%) # | 5 (12%) $ | 1.00 |
| Within 1 month [number (%)] | 0 (0%) # | 9 (22%) $ | 0.56 |
| Within 3 months [number (%)] | 0 (0%) # | 11 (27%) $ | 0.32 |
| Within 6 months [number (%)] | 4 (80%) # | 30 (73%) $ | 1.00 |
| Within 12 months [number (%)] | 5 (100%) # | 32 (78%) $ | 0.57 |

Categorical variables were compared using the Fisher's exact test and presented as number (%). Statistically significant results are marked in bold

*Data available for 104 patients

#Data available for five out of seven patients with neurologic deficit

$Data available for 41 out of 48 patients with neurologic deficit

**Table 3** Selected long-term consequences of the patients included in the study

| Characteristic | With vascular surgery ($n=11$) | Without vascular surgery ($n=114$) | $p$ value |
|---|---|---|---|
| Long-term neurologic deficit | 1 (9%) | 25 (22%) | 0.46 |
| Long-term circulatory deficit | 1 (9%) | 8 (7%) | 0.57 |

Categorical variables were compared using the Fisher's exact test. Categorical variables are presented as number (%)

vascular or neurological outcomes were observed between the two groups.

The timing of surgical treatment after displaced SCHF has frequently been discussed. Early reduction and treatment are also generally recommended for SCHFs. However, many studies have addressed this issue and some refuse this approach. Based on a questionnaire study of 309 pediatric orthopedics in the United States, Carter [15] found that 81% of them preferred a simple reduction of the displaced SCHF, the application of a cast, and postponement of surgery until the following day. Similarly, in his literature review and meta-analysis of more than 1,500 SCHFs, Farrow [16] found no statistically significant difference in patients operated on early (within 12 h of injury) and delayed in terms of the need for open reduction, iatrogenic nerve injury, associated compartment syndrome, postoperative vascular deficits, the need for a secondary operation, or postoperative deformity in long-term follow-ups. In our study, all patients with SCHFs and concomitant pulseless pale neurovascular injury were promptly operated on. For the patients with pulseless pink type SCHF with a warm and red periphery of the extremity, the time factors between injury and surgery were compared. No statistically significant differences were found between the group of patients who underwent vascular surgery and those for whom closed fracture reduction, stabilization of the fracture, and subsequent observation were sufficient. Therefore, a longer time interval between injury and definitive treatment is also not an indication for vascular surgery. The results of our study showed only an earlier recovery of pulsation on *a. radialis* in a group of patients who underwent vascular surgery. This finding is consistent with some previous studies. In a single-center study, Babala [17] reported on 11 patients with pulseless SCHF, all of whom underwent open vascular surgery. In four patients thrombectomy was made, in two replacement of the brachial artery by venous graft was performed and for the remaining patients, the deliberation of vascular structures was sufficient. Louahem [12] reported on 63 patients with pulseless pink SCHFs. After fracture reduction, non-palpable pulsation of the radial artery persisted in 21 patients, and all of them underwent open vascular revision, most of which involved just a deliberation of a vessel or thrombectomy. For early pulsation recovery, Babala and Louahem recommended vascular surgery in all patients with pulseless SCHF.

Many authors have noted number of nerve injuries associated with pulseless SCHF. This is mainly due to the higher energy of the trauma and the type of fracture. In a single-center study, Rasool et al. described 27 patients with pulseless SCHFs, 18 of whom had a neurovascular bundle inserted and stretched over a ventral tip of the fracture [18]. In his study, Lim even evaluated the angle of the tip [19]. In both cases, this type of severely displaced SCHF increased the risk of neurovascular injury.

In a multicenter study, Harris followed 71 patients with pulseless SCHF and concomitant median nerve injury. The conclusion of his study demonstrates a significantly longer time of recovery of neurological function and greater risk of compartment syndrome in a conservative treatment. In this combination of injuries, he recommends an active approach, open reduction and vascular revision [20]. Magnat reached a similar conclusion in his monocentric study of 19 patients with pulseless pink SCHF [21]. In our study, a significantly higher number of patients with concomitant nerve injury also underwent a vascular surgery. However, no significant difference was found regarding the time of restoration of the neurological function between groups with or without vascular surgery.

The basic question regarding the benefit of vascular surgery in pulseless pink SCHFs in terms of long-term neurological and vascular outcomes and consequences, therefore, remains.

Konstantiniuk [9], in his 15-year monocentric study, also followed 12 patients with pulseless pink fractures who received open revisions of the injured vessel. According to the clinical findings and Doppler ultrasound examinations, the results were excellent with maintained perfusion of the brachial artery; therefore, he recommended an active approach to injured blood vessels. An extensive study of 840 patients with severely displaced SCHFs (Gartland III) was also conducted by Noamann [10]. Of the total patients, 120 had non-palpable radial artery pulsations, and after closed fracture reduction, pulsation in the periphery of the extremity resumed in 89 of those patients. The remaining 31 patients underwent open surgical vascular revision, and he concluded that the results during the postoperative period were excellent. No Volkmann contracture was noted, no compartment syndrome occurred, and the elbow joint position and range of motion were good. Several case reports have been published recommending an active approach and open vascular examination in all pulseless SCHFs [22, 23]. On the opposite, some authors reported complications occurring in the postoperative period after vascular reconstructions. However, Babala [17] mentioned the need for three re-operations in 11 patients, Preis [13] described 36.4% of wound healing complications and 45.5% postoperative restrictions of brachial artery flow on ultrasound Doppler or angiography examination after vascular surgery. In addition, vascular surgery certainly prolongs the length of the child's overall stay in the operation room and requires the presence of an experienced vascular surgeon in the treatment of this injury.

Therefore, many authors favor a conservative strategy in the treatment of pink pulseless SCHFs. This conservative procedure, sometimes called "watchful waiting", is based on the knowledge of the collateral vascular system in the upper extremity and the excellent experience of many authors with this approach. The existence of a good vascular supply to the periphery of the upper extremity at the ligation of the brachial artery was described in the last century by Lally [24]. This conservative approach was also supported by Choi [25] in his large monocentric study of 1255 patients with SCHF and 24 pulseless pink supracondylar fractures after primary fracture reduction and K-wire fixation. Although the conservative procedure never led to a complete immediate recovery of pulsation of the radial artery in half of the patients, the morphological and functional findings on the limb after treatment were excellent. Similarly, Weller [26] published a multicenter study of 1297 patients with displaced SCHFs. The 44 of them had pulseless SCHF, 20 patients had warm and red periphery of the extremity without pulsation on radial artery after fracture reduction. All were treated conservatively and only one patient required a vascular reconstruction for vascular compromise, which did appear until nine hours after fracture reduction. All patients with pulseless pink SCHFs had good results, without sequelae. The results of our study confirm this approach, and no statistically significant benefit of vascular reconstruction performance in pulseless pink fractures was observed in the evaluation of long-term outcomes and consequences. However, a clear algorithm for treating patients with pulseless pink SCHF has not been set up yet and recommendations remain controversial. Similarly, the conclusions of the members of the Pediatric Orthopedic Society of North America (POSNA) and the American Academy of Orthopedic Surgeons (AAOS) are not uniform, according to studies presented by White and Sanders [7, 27].

The strength of this study is the relatively large cohort of patient with precisely defined clinical phenotypes of SCHF. Second, not only obvious short-term outcomes but also long-term outcomes were collected in this study. This study also has a limitation that is worth mentioning. The subgroup of the patients who underwent vascular surgery has a very small sample size. In addition, these patients had a higher rate of nerve injury than those who underwent no vascular surgery. Despite the fact, that the decision on the necessity of vascular surgery was made only based on the clinician’s discretion, we cannot fully exclude a potential selection bias. We are fully aware that a clear answer to the question of whether patients with a pink pulseless SCHFs should undergo vascular surgery may be determined by a randomized controlled trial but could not be determined in this study. This study, however, provides clinically important and valuable data concerning the outcomes of patients with pink pulseless SCHFs based on treatment strategy.

## Conclusion

In this study, vascular surgery for patients with the pink type of pulseless SCHFs was associated with a more prompt restoration of radial artery pulsation. However, the study results did not confirm any statistically significant benefits of vascular surgery in terms of neurological deficits restoration or occurrence of long-term neurological and circulatory deficits.

**Acknowledgements** The authors thank the patient and his parents for granting permission to publish data. All data were processed anonymously in accordance with GDPR. The ethical rights of individual subjects were not violated during data collection and evaluation.

**Language**: revision by language editing service—Elsevier.

**Author contributions** As the principal investigator, RS had full access to all study data and takes responsibility for the integrity of the data and the accuracy of the data analysis in tight cooperation with LP. Study concept, design and experiments were performed by RS, LP, JP. Data analysis was made by RS, JT, LP. Drafting of the manuscript and critical revision was executed by RS, LP, JP. All authors checked, approved the final manuscript and agree with submission.

**Funding** Additional support was received from the University Hospital in Hradec Králové (a long-term organization development plan).

**Availability of data and materials** All data, that are included in the analysis and from which the conclusions are drawn are available in the Department of Paediatric Surgery, University Hospital, Sokolská 581, 500 05 Hradec Králové, Czech Republic.

### Declarations

**Conflict of interest** The authors declare no conflicts of interest regarding the publication of this article.

## References

1. Skaggs DL, Flynn JM (2015) Supracondylar fractures of the distal humerus. In: Rockwood and Wilkins' Fractures in children. 8th edition. Lippincot Wolters Kluwer Health, Philadelphia: 581–629
2. Havránek P, et al. Supracondylar humerus fracture. In: Havránek P, et al., editors. Paediatric fracture (in Czech). Praha: Galén; 2013. p. 112–34.
3. Emery KH, Zingula SN, Anton CG, Salisbury SR, Tamai J. Pediatric elbow fractures: a new angle on an old topic. Pediatr Radiol. 2016;46(1):61–6. https://doi.org/10.1007/s00247-015-3439-0.
4. Scannell BP, Brighton BK, VanderHave KL. Neurological and vascular complications associated with supracondylar humeral fractures in children. JBJS Reviews. 2015;3(12): e2. https://doi.org/10.2106/JBJS.RvW.N.00084.
5. Štichhauer R, Preis J, Kanta M, Krobot J. Nerve Injuries in Supracondylar Humeral Fractures in Children (in Czech). Cesk Slovak Neurol N. 2017;113(4):440–5. https://doi.org/10.14735/amcsnn2017440.
6. Aksakal M, Ermutlu C, Sarisözen B, Akesen B. Approach to supracondylar humerus fractures with neurovascular compromise in children. Acta Orthop Traumatol Turc. 2013;47:244–9. https://doi.org/10.3944/AOTT.2013.3012.
7. White L, Mehlman ChT, Crawford AH. Perfused, pulseless, and puzzling: a systematic review of vascular injuries in pediatric supracondylar humerus fractures and results of a POSNA questionnaire. J Pediatr Orthop. 2010;30:328–35. https://doi.org/10.1097/BPO.0b013e3181da0452.
8. Leiblein M, Lustenberger T, Schulz AK, Schmitz-Rixen T, Marzi I. Neurovascular complications after supracondylar humerus fractures in children. Trauma Case rep. 2017;8:16–9. https://doi.org/10.1016/j.tcr.2017.01.013.
9. Konstantiniuk P, Fritz G, Ott T, Weiglhofer U, Schweiger S, Cohnert T. Long-term follow-up of vascular reconstructions after supracondylar humerus fracture with vascular lesion in children. Eur J Vasc Surg. 2011;42:684–8. https://doi.org/10.1016/j.ejvs.2011.06.028.
10. Noaman HH. Microsurgical reconstruction of brachial artery injuries in displaced supracondylar fracture humerus in children. Microsurgery. 2006;26:498–505. https://doi.org/10.1002/micr.20277.
11. Brahmamdam P, Plummer M, Modral JG, Megison SM, Clagett P, Velantine RJ. Hand ischemia associated with elbow trauma in children. J Vasc Surg. 2011;54(3):773–8. https://doi.org/10.1016/j.jvs.2011.03.004.
12. Louahem D, Cottalorda J. Acute ischemia and pink pulseless hand in 68 of 404 Gartland type III supracondylar humeral fractures in chidren: urgent management and therapeutic consensus. Injury Int J Care Injured. 2016;47:848–52. https://doi.org/10.1016/j.injury.2016.01.010.
13. Preis J, Rejtar P. Significance of the radial artery pulse in dislocated supracondylar fractures of the humerus in children (in Czech). Rozhl Chir. 2000;79:348–56.
14. Shaw BA, Kasser JR, Emans JB. Rand FF Management of vascular injuries in displaced supracondylar humerus fractures without arteriography. J Orthop Trauma. 1990;4:25–9.
15. Carter CT, Bertrand SL, Cearlex CM. Management of pediatric type III supracondylar humerus fractures in the United States: results of a national survey of pediatric orthopaedic surgeons. J Pediatr Orthop. 2013;33:750–4. https://doi.org/10.1097/BPO.0b013e31829f92f3.
16. Farrow L, Ablett AD, Mills L, Barker S. Early versus delayed surgery for paediatric supracondylar humeral fractures in the absence of vascular compromise. Bone Join J. 2018;100-B:1535–41. https://doi.org/10.1302/0301-620X.100B12.
17. Babala J, Horn F, Sýkora L, et al. Supracondylar humerus fracture with vascular injury (in Czech). Rozhl Chir. 2001;10:545–8.
18. Rasool MN, Naidoo KS. Supracondylar fractures posterolateral type with brachialis muscle penetration and neurovascular injury. J Pediatr Orthop. 1999;19:518–22. https://doi.org/10.1097/00004694-1999070000-000019.
19. Lim KBL, Lim CT, Tawng DK. Supracondylar humeral fractures in children, beware the medial spike angle. Bone Join J. 2013;95B:1290–4. https://doi.org/10.1302/0301-620X.95B9.
20. Harris LR, Arkader A, Broom A, et al. Pulseless supracondylar humerus fracture with anterior interosseous nerve or median nerve injury—an absolute indication for open reduction? J Pediatr Orthop. 2019;39:1–7. https://doi.org/10.1097/BPO.000000000000000001238.

21. Mangat KS, Martin AG, Bache CE. The 'pulseless pink' hand after supracondylar fracture of the humerus in children. The predictive value of nerve palsy. J Bone Joint Surg Br. 2009;91:1521–5. https://doi.org/10.1302/0301-620X.91B11.22486.
22. Kálal J, Šťastný E, Trč T. Vascular complication in treatment of supracondylar fractures in children—three causes (in Czech). Ortopedie. 2013;7:193–6.
23. Erhart S, Lutz M, Larcher P, Blauth M, Attal R. A case of supracondylar humerus fracture with vascular impairment. Open it up? Arch Orthop Trauma Surg. 2013;133:835–9. https://doi.org/10.1007/s00402-013-1743-4.
24. Lally KP, Foster CE 3rd, Chwals WJ, Brennan P, Aktinson JB. Long-term follow-up of brachial artery ligation in children. Ann Surg. 1990;212(2):194–6. https://doi.org/10.1097/00000658-199008000-00013.
25. Choi PD, Melikian R, Skaggs DL. Risk factors for vascular repair and compartment syndrome in the pulseless supracondylar humerus fracture in children. J Pediatr Orthop. 2010;30:50–6.
26. Weller A, Garg S, Larson AN, et al. Management of the pediatric pulseless supracondylar humeral fracture: is vascular exploration necessary? J Bone Joint Surg Am. 2013;95:1906–12. https://doi.org/10.2106/JBJS.L.01580.
27. Sanders JO, Heggeness MH, Murray JN, Pezold RC, Sevarino KS. Management of pediatric supracondylar humerus fractures with vascular injury. J Am Acad Orthop Surg. 2016;24:e21–3. https://doi.org/10.5435/JAAOS-D-1500701.