

Paediatric Humeral Shaft Fractures: An Overview and Modern Management Approach

Raza M¹, Iossifidis Anestis¹

¹ Department of Trauma & Orthopaedic Surgery, Croydon University Hospital, London, UK.

Conflict-of-interest statement: The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

Open-Access: This article is an open-access article which was selected by an in-house editor and fully peer-reviewed by external reviewers. It is distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>

Correspondence to: Anestis Iossifidis, MD, FRCS Ed, FRCS Ed (orth.) Senior Orthopaedic Surgeon, Croydon University Hospital, 530 London Road, Croydon, London, CR7 7YE, UK.
Email: anestis.iossifidis@gmail.com
Telephone: +0044 (0) 7802404708

Received: February 5, 2021

Revised: March 1, 2021

Accepted: March 3 2021

Published online: April 28, 2021

ABSTRACT

Paediatric humeral shaft fractures are a relatively uncommon injury comprising less than 3% of all paediatric fractures. Although these injuries are uncommon, it is important to be familiar with managing such injuries and recognising which types of fractures require surgical stabilisation or referral to specialist tertiary care. This paper provides a broad overview of humeral diaphyseal fractures in children including key management principles. We discuss aetiology, non-accidental trauma (NAT), clinical findings, imaging, fracture patterns, classification, associated injuries, management (non-operative and operative) and complications. Due to the increasing trend of managing these injuries with surgical fixation, we also review the recent available literature evaluating these surgical options. Overall, there is good evidence that the majority of humeral shaft fractures in children and adolescents can be successfully managed

non-operatively. However, operative management when clinically indicated, especially in older children and adolescents, has shown to be beneficial with good clinical outcomes and low complication rates. Further research with paediatric-specific core outcomes is recommended to further evaluate this underrepresented topic.

Key words: Paediatric; Humerus; Shaft; Diaphysis; Fracture; Management

© 2021 The Author(s). Published by ACT Publishing Group Ltd. All rights reserved.

Raza M, Iossifidis A. Paediatric Humeral Shaft Fractures: An Overview and Modern Management Approach. *International Journal of Orthopaedics* 2021; 8(2): 1441-1446 Available from: URL: <http://www.ghrnet.org/index.php/ijo/article/view/3135>

INTRODUCTION

Fractures are common in children with up to one third of all children sustaining at least one fracture aged 16 or under^[1]. Humeral shaft fractures in children are a relatively uncommon injury estimated at between 0.4 and 3% of all paediatric fractures^[2-4]. They account for approximately 20% of all humeral fractures and have a bimodal distribution with the majority occurring before age 3 and after 12 years of age^[5-7]. Consequently, there is limited evidence in the literature for optimally managing such injuries.

The aim of this paper is to provide a clear narrative overview of this underrepresented injury. We discuss aetiology, non-accidental trauma (NAT), clinical findings, imaging, fracture patterns, classification, associated injuries, management and complications. We aim to increase awareness of the management of such injuries in a standard acute trauma unit and when to refer for specialist paediatric tertiary care unit. Due to the increasing trend of managing these injuries with surgical fixation we have reviewed the recent available literature evaluating these surgical options.

AETIOLOGY

There are various causes of humeral diaphyseal fractures in children according to their age group.

At birth

Humeral shaft fractures are the second commonest birth-related fracture, after clavicle^[8]. At birth, such fractures can be caused by factors such as macrosomia, breech delivery or prolonged/difficult delivery with rotation or hyperextension of the upper arm^[5-7,9]. In addition, a recent paper reported additional statistically significant increased risk factors including maternal obesity, shoulder dystocia, multiple birth, pre-term birth and high birth weight (> 4000g)^[10].

In older children

Humeral shaft fractures can be caused by direct trauma to the arm, falls, road traffic collisions or sporting injuries^[5-7,9]. Up to 56% of humeral shaft fractures in older children are caused by falls^[10]. Due to the rising popularity in extreme sports, increasing prevalence of paediatric fractures related to skateboarding, skiing, mountain biking, trampolining and martial arts has been reported^[11,12]. A recent Finnish study showed up to 30% of all humeral shaft fractures resulted from trampolining and skiing accidents^[13].

At all ages

1. Pathological fractures

These should be considered in cases of low-energy trauma such as fracture through common simple bone cysts or less common with bone fragility conditions such as osteogenesis imperfecta, fibrous dysplasia, scurvy and osteopetrosis^[3,7]. In a large review paper analysing the Swedish birth population of over 1.8 million between 1997 and 2014, they found an incidence of bone fragility disorders of 1% in birth-related humeral shaft fractures and 6% in later fractures^[10].

2. Non-accidental Trauma

Non-accidental trauma (NAT) is an important consideration for paediatric fractures at any age. Loder and Bookout^[14] reported the humerus to be the second most common long bone injury in NAT after the tibia. A systematic review paper looking at patterns of skeletal fractures in child abuse under 3 reported an overall estimate of the probability of suspected abuse at 0.54 (0.30 to 0.88)^[15]. Rates of humeral fractures attributable to NAT have been reported in 43% to 73% of children aged 12 months or under while rates decreased to between 9.3% and 12% from ages 1 to 3^[16,17].

In particular, spiral humeral shaft fractures have been reported to be the commonest fracture pattern associated with abuse^[18,19]. In a retrospective 10-year review of all humerus fractures in children aged up to 48 months at a level 1 paediatric trauma centre, 86.7% resulted from NAT^[18]. They also reported 31.54 greater odds of being the victim of abuse in children presenting with a humerus fracture below the age of 18 months, which is typically considered younger than walking age.

The consequences of missing a child with NAT places them at increased risk of morbidity and mortality without involvement of protective services^[18]. Taitz *et al*^[20] discuss various indicators to help guide clinical judgment in determining whether a long bone fracture may represent abuse. These include: inconsistent history, young age, presence of polytrauma, unreasonable or unexplained delay in presentation, unwitnessed injury and previous fractures and/or emergency department attendances^[20]. The Canadian Paediatric Society also highlight humerus fractures in less than 18-month-old children as a red flag high-risk factor^[21].

As such, these should be taken into consideration when assessing a child presenting with humeral shaft fractures and NAT must always be a potential differential especially in the younger age group. Thorough clinical and radiographic evaluation (such as skeletal

survey or bone scan) should be considered in suspected cases and local protocols followed in respect to referral to appropriate safeguarding bodies^[21].

CLINICAL FINDINGS

Symptoms are dependent on the age of the child and mechanism of injury. In newborns with birth-related trauma, the only obvious finding may be pseudoparalysis with the child's refusal to use the arm^[3,9]. Further examination can identify tenderness, instability of the humeral shaft and crepitus at the fracture site^[5-7].

Older children typically present with pain, swelling and bruising. The child may be found to splint the arm against the body to reduce mobility. Examination can reveal obvious deformity as well as pain or crepitus on palpation^[5-7]. However, most humeral shaft fractures do not have a visible deformity and are minimally displaced on radiographs^[8].

Neurovascular injury is rare, but examination is vital as with any paediatric limb fracture. Examination of the whole limb is also indicated to exclude presence of an ipsilateral forearm fracture causing a 'floating elbow' with a higher prevalence in high-energy injuries and polytrauma. As with any child presenting with a fracture, it is also important to generally examine the child to exclude signs of NAT.

IMAGING

For the vast majority of paediatric humeral shaft fractures, radiographic imaging with standard full length anterior-posterior (AP) and lateral views are sufficient. The joint above and below should be adequately imaged and if not then dedicated shoulder and elbow series should be performed^[8]. Of note, there is often a prominent vascular groove seen in the distal humerus which is a normal finding and should not be confused with a fracture^[9,22]. Care should be taken when reviewing such imaging to exclude underlying causes such as bone cysts for pathological fractures. Further detailed imaging may then be required in such circumstances^[5-7].

FRACTURE PATTERNS

Fracture patterns vary dependent on age. In general, transverse and short oblique fractures result from direct trauma. Spiral fractures are usually caused by an indirect twisting injury, usually from a fall. However, as previously noted, spiral fractures are a potential risk factor for NAT and careful assessment should be undertaken especially in any infant or toddler presenting with such injury^[18-21,23].

Paediatric humeral shaft fractures are located distal to the deltoid insertion which, in combination with the rotator cuff muscles, displaces the proximal fragment in abduction (anteriorly and laterally). The distal fragment is usually shortened and displaced medially due to the action of triceps and biceps and frequently internally rotated due to the child holding the arm across the chest^[7,8].

CLASSIFICATION

Traditionally, there were no widely accepted paediatric-specific classification systems for humeral shaft fractures. Standard classification was based on diaphyseal fracture principles including: (1) Anatomical location (proximal, middle or distal third); (2) Fracture pattern (spiral, oblique, transverse or comminuted); (3) Degree of displacement; (4) Open/closed^[3,23].

The AO Paediatric comprehensive classification system for long

bone fractures (AO PCCF) was introduced in 2007 based on fracture location and morphology^[24]. Diaphyseal humerus fractures are coded as '12-D' (1 for humerus, 2-D for diaphyseal) and can be further classified based on whether the fracture is complete transverse (≤ 30 degrees) or complete oblique or spiral (≥ 30 degrees) as 12-D/4 or 12-D/5 respectively. Additional classification is based upon whether the fracture pattern is simple (e.g. 12-D/4.1) or multi-fragmentary (e.g. 12-D/4.2).

As part of its validation process, the AO PCCF was used to review 2292 upper extremity fractures in children and adolescents. The 2017 paper concluded that the classification can be comprehensively used to describe such fractures, but prospective multicentre clinical studies are required to assess its clinical relevance for treatment decisions and prognostic outcomes for full validation^[25,26].

ASSOCIATED INJURIES

Paediatric humeral shaft fractures can rarely be associated with nerve palsy and vessel injury^[5-7].

Nerve injuries are uncommon with radial nerve palsy associated in up to 5% of humeral shaft fractures in children^[5-7]. It can be due to contusion, kinking or entrapment of the nerve in the fracture site rather than complete laceration^[3,6]. It is thought that the thick periosteum may have a protective effect on the nerve and reduces risk of laceration or entrapment within the fracture site^[6]. Radial nerve injury would cause numbness to the dorsum of the hand (first dorsal web space) as well as motor deficit in thumb/wrist extension and forearm supination^[7,27].

These should primarily be managed conservatively with wrist splints and physical therapy to prevent wrist contractures^[7,9]. Prognosis is usually excellent with nerve function usually fully resolving^[3,6,9,28]. If there is no recovery at 3 months, it is advised to evaluate with electromyogram and nerve conduction velocity studies^[7,8]. In the context of radial nerve injury in open fractures, radial nerve exploration is recommended with early repair advised^[6].

Vascular injury is rare but if present requires immediate evaluation and treatment to restore vascularity to the limb^[5-7]. The surgical team must be competent to perform the operation and urgent referral to a specialist unit may be required depending on local protocols. Humeral shaft fractures requiring vascular repair are usually an indication for ORIF or external fixation^[5-7]. Compartment syndrome is also uncommon in the context of paediatric humeral shaft fractures but should be monitored for especially in the context of high energy and vascular injuries^[6].

REFERRAL TO SPECIALIST CARE

As this injury is uncommon, it is important to recognise when referral to specialist care may be clinically indicated. These include polytrauma, open fractures and suspected vascular injury. There is clear guidance that paediatric polytrauma should be managed at a paediatric-specific trauma centre as outcomes are significantly better^[29-32]. These patients should be managed with paediatric medical and surgical specialists with the resources to deal with complex requirements of a traumatised child including paediatric-specific surgical operating theatres, intensive care units and rehabilitation services^[31].

Open fractures are recommended to be managed at centres with combined orthopaedic and plastic surgical specialties^[32,33]. There is also clear guidance that fractures with arterial injury should also be immediately referred to a specialist centre with both orthopaedic and vascular surgical capabilities^[32,34]. As such, in the context of

paediatric humeral shaft fractures that are open and/or have vascular injury, immediate referral to a specialist unit is indicated.

TREATMENT

Non-operative

The vast majority of paediatric humeral shaft fractures can be managed non-operatively. Due to the great remodelling potential of paediatric bones and thick periosteum, generally acceptable alignment for humeral shaft fractures include 20 degrees of coronal plane angulation (varus/valgus), 20 degrees of sagittal plane angulation (procurvatum), 15 degrees of rotation and up to 1-2cm of shortening^[5-7].

Beaty^[35] reports that with younger children, these ranges can be much more flexible. He describes an age-based algorithm for acceptable displacement and angulation: for children under 5, 70 degrees of angulation and total displacement; for children 5 to 12, 40 to 70 degrees of angulation; and for children older than 12, 40 degrees of angulation. He also reports that 50% apposition is acceptable in children older than 12 and shortening of 1-2 cm is well tolerated with lack of clinical deformity being more important than radiographic alignment^[8,35].

For newborns, regardless of the severity of angulation or displacement, closed fractures are managed by simple splinting of the arm to the chest via bandaging or a swathe for two to four weeks^[3,7-9]. Parents should be reassured that the fracture will rapidly and reliably heal, and the child will usually go on to have a fully functional arm. Follow-up should continue past when the fracture has healed to assess for brachial plexus function and potential nerve injury^[7,8].

For children and adolescents, there are multiple techniques of immobilisation, such as a sling and/or swathe, velpeau bandage, collar and cuff, coaptation splint (e.g. sugar-tong splint) or hanging arm cast^[3,5,7,9,23]. Gravity assists with alignment of the fracture via traction of the arm and subsequently improves patient comfort^[3,6,9].

Functional bracing can also be utilised and is often beneficial once pain has subsided after an initial 7-10 days in older children and adolescents. They are lightweight, easy to apply and allow for earlier elbow range of motion^[5,6].

Weekly check radiographs for the first 3 weeks are advisable to ensure satisfactory alignment^[3]. Immobilisation is continued in children until adequate callus is seen on check radiographs. In children this is typically up to 4 weeks^[9] and in adolescents up to 6-8 weeks^[5-7]. Circumduction and pendulum exercises for the shoulder are recommended as soon as pain allows, often after 2 to 3 weeks^[7].

It is also advisable to delay return to sports for up to 3 months depending on age of the child and degree of healing due to potential risk of re-fracture^[3,5-7]. In cases of residual deformity, it is advised to perform check radiographs 6 monthly to check for remodelling^[3].

Operative

Age and remodelling potential also play an important role in deciding when to manage these fractures operatively with surgical management predominantly being utilised in older children and adolescents. Humeral diaphyseal fractures also have lower remodelling potential compared to other fractures (such as proximal humerus fractures) due to the increased distance from the physis^[36,37]. Operative management of paediatric humeral shaft fractures is indicated in the following: open fractures, fractures with associated vascular injuries, bilateral fractures, floating elbow, comminuted fractures, compartment syndrome and closed fractures when acceptable displacement or angulation cannot be managed with non-

operative methods^[3-7,9]. Polytrauma patients are a relative indication for surgical fixation to allow early mobilisation^[5-7,30,31].

Surgical options include open reduction internal fixation (ORIF), intramedullary (IM) nailing or external fixation. The latter is primarily indicated for open fractures with extensive soft tissue or bone loss or critically unwell polytrauma patients^[5-7,38].

ORIF can be performed with 3.5 or 4.5mm plates depending on patient size^[5,6]. Approaches via an anterolateral, direct lateral or posterolateral approach are dependent on fracture pattern and surgeon preference. Care must be taken to avoid damage to the radial nerve and ensuring the nerve is not entrapped under the plate. Fixation of six cortices above and below the fracture are also advised for stability^[5,6]. ORIF is also the recommended surgical choice when there is associated vascular injury to avoid fracture displacement that can disrupt vascular anastomoses^[3].

IM nailing is a surgical option for transverse or short oblique fractures (length-stable fractures). Indirect reduction is first performed, and this option is advantageous as surgical incisions are smaller as is surgical dissection^[5-7]. Antegrade or retrograde approach should be considered (depending on fracture pattern) with care taken to avoid the physis to prevent growth arrest^[3,39].

COMPLICATIONS

Relevant complications of non-operative and operative management of paediatric humeral shaft fractures can include malunion or non-union and limb-length discrepancy.

Malunion or non-union is uncommon due to excellent bone healing and remodelling potential in children. In addition, compensatory range of motion at the shoulder and elbow allows function-limiting malunion to be rare^[5-7]. If non-union does occur, ORIF is generally recommended^[6-7].

Limb-length discrepancy can occur with non-operative and operative management of diaphyseal fractures but again these rarely cause any functional deficit. Generally, up to 6-8cm of shortening can be well tolerated without functional loss and overgrowth can occur but is usually less than 1cm^[6]. If there is significant limb length discrepancy and functional compromise, humeral lengthening via distraction osteogenesis can be considered^[6].

DISCUSSION

Paediatric humeral shaft fractures are uncommon and as such there is limited data in the literature comparing management options.

There has been an increasing trend towards managing these injuries with operative fixation rather than the traditional conservative management^[13,39]. Kosuge and Barry^[40] highlight changing trends towards paediatric fracture management being influenced by such factors as increased societal expectation of a 'perfect result', cosmesis, increased litigation and reduced hospital stay. In older children and adolescents, particularly those with keen sporting interests, surgical fixation of humeral shaft fractures is increasingly considered for earlier functional and cast-free follow-up and potential quicker return to sport^[39,41,42].

Hannonen *et al*^[13] reported a significant increased trend of managing humeral shaft fractures operatively in their analysis of 88 humeral shaft fractures over a 15-year period. Interestingly, they found no significant change in patients' or fractures' characteristics during that time period that could have explained the trend. They concluded that the increased use of surgical management for such injuries was due to a lower threshold for surgery towards the end of the study period despite limited available evidence in the literature.

This may in part be influenced by recent studies reporting good outcomes for humeral shaft fractures with surgical fixation^[4,13,37,41-47].

In one of the largest available cohort studies, O'Shaughnessy *et al*^[4] (2019) retrospectively reviewed their management of 80 paediatric humeral shaft fractures over a 20-year period (mean age 10). In total, 19% of their fractures were managed with surgical stabilisation, a similar figure reported by other large retrospective studies^[13]. The majority of the operated group were treated with plate fixation, followed by flexible IM nailing, and were found to be in older children with higher-energy injuries, open fractures and increased fracture displacement. When comparing the operated group to the non-operated group, all patients were found to progress to union with minimal complications. They concluded that non-operative management was successful in the majority of patients and that operative stabilisation (when rarely indicated) was successful in progression to union, improved radiographic alignment and had low complication rates^[4].

In their multicentre comparative study, Canavese *et al*^[43] (2017) reviewed a total of 36 children (mean age 10.8) with humeral shaft fracture managed either conservatively (bandaging), with external fixation or elastic nailing. Their findings showed that surgical treatment resulted in better radiologic outcome, less post-treatment pain and faster mobilisation than the non-operatively managed group. However, there was no difference in clinical outcomes with all patients regaining full range of motion and function with comparable patient reported outcome scores on last follow-up. In addition, all fractures regardless of management went on to fully heal and complication rates between the groups were similar. The authors conclude that non-operative treatment was as effective as surgical treatment apart from length of time for immobilisation.

Other studies have also reported good outcomes for operative management in particular with flexible IM nailing.

Pogorelic *et al*^[42] (2017) retrospectively reviewed 41 humeral shaft fractures in children (mean age 12) managed with flexible IM nailing. All patients had progressed to complete radiographic union at 9 weeks. Four minor complications were noted (2 radial nerve neuropraxias, 2 entry site skin irritation/infections) which fully resolved. The authors concluded that this minimally invasive technique allows early functional and cast-free follow-up with quick pain reduction.

Similarly, Marengo *et al*^[37] (2016) evaluated 38 patients (mean age 11.1) who underwent elastic stable intramedullary nailing (ESIN) for their humeral shaft fractures. After mean follow-up of 30 months (all hardware removed), all fractures had healed with 3 patients having mild residual deformity but good overall functional activity.

Fernandez *et al*^[41] (2010) reviewed 31 children (mean age 11.4) who underwent flexible IM nailing and reported excellent objective and subjective outcomes with full return to activity and positive cosmetic results. As part of their larger study, Zivanovic *et al*^[36] (2018) reviewed 12 children (mean age 12.6) with humeral shaft fractures who underwent ESIN with half due to open fractures or polytrauma. At last follow-up, all patients had full range of motion and 83% resumed previous activity level. The remaining 17% had physical and sports activity limitations due to other polytraumatic injuries unrelated to the humeral fracture.

Garg *et al*^[44] (2009) retrospectively reviewed all paediatric humeral shaft fractures over a 15 year period (total 13, mean age 12) and found that titanium elastic nail (TEN) fixation was effective with a high rate of union and low rate of complications, namely nail migration. Abosalim *et al*^[45] (2014) established full union rates with no intra-operative complications but reported a 10% superficial

wound infection rate and 5% nail migration rate in their series of 20 patients (mean age 10).

Similarly, Kwak *et al.*^[46] (2012) reported on their series of 12 patients (mean age 12.3) who underwent TEN fixation. They reported full union rates and a full return to normal activity at latest follow-up. However, 17% of patients required early removal of nails due to pain, discomfort or skin irritation. To this end, surgical technique and experience is key to minimising such complications.

Overall, there appears to be good evidence that the majority of humeral shaft fractures in children and adolescents can be successfully managed non-operatively. However, operative management when clinically indicated, especially in older children and adolescents, has shown to be beneficial with good clinical outcomes and low complication rates.

CONCLUSIONS

This paper has provided a broad overview of paediatric humeral shaft fracture management looking at aetiology, NAT, clinical findings, imaging, fracture patterns, classification, associated injuries, management (non-operative and operative) and complications. In view of the increasing trend towards surgical management, this paper has also evaluated surgical options for these fractures with overall good clinical outcomes and low complication rates.

Although these injuries are uncommon, it is important to be familiar with managing such injuries and recognising which types of fractures require surgical stabilisation. There is evidence for both non-operative and operative management of these injuries but further research with paediatric-specific core outcomes is recommended.

REFERENCES

- Cooper C, Dennison EM, Leufkens HGM, Bishop N, Van Staa TP. Epidemiology of childhood fractures in Britain: A study using the general practice research database. *J Bone Miner Res.* 2004; **19**(12): 1976-81. [PMID: 15537440]; [DOI: 10.1359/JBMR.040902]
- Rennie L, Court-Brown CM, Mok JYQ, Beattie TF. The epidemiology of fractures in children. *Injury.* 2007; **38**(8): 913-22. [PMID: 17628559]; [DOI: 10.1016/j.injury.2007.01.036]
- Caviglia H, Garrido CP, Palazzi FF, Meana NV. Pediatric fractures of the humerus. *Clin Orthop Relat Res.* 2005; **(432)**: 49-56. [PMID: 15738803]; [DOI: 10.1097/01.blo.0000156452.91271.fb]
- O'Shaughnessy MA, Parry JA, Liu H, Stans AA, Larson AN, Milbrandt TA. Management of paediatric humeral shaft fractures and associated nerve palsy. *J Child Orthop.* 2019; **13**(5): 508-15. [PMID: 31695818]; [PMCID: PMC6808073]; [DOI: 10.1302/1863-2548.13.190012]
- Rush J. Pediatric Orthopaedic Society of North America (POSNA): Humeral Shaft Fractures. 2021. Available from: URL: <https://posna.org/Physician-Education/Study-Guide/Humeral-Shaft-Fractures>
- Bae DS. Humeral Shaft and Proximal Humerus, Shoulder Dislocation. In: Flynn JM, Skaggs DL, Waters PM, eds. *Fractures in Children*. 8th ed. Philadelphia: Wolters Kluwer; 2015: 784-99.
- Herring JA, Ho C. Upper Extremity Injuries. In: Herring JA, ed. *Tachdjian's Pediatric Orthopaedics*. 5th ed. Philadelphia: Elsevier Saunders; 2014: 1262-4
- Shrader MW. Proximal Humerus and Humeral Shaft Fractures in Children. *Hand Clin.* 2007; **23**(4): 431-5. [PMID: 18054670]; [DOI: 10.1016/j.hcl.2007.09.002]
- Ryan LM, Boutis K, Wiley J. UpToDate: Midshaft Humeral Fractures in Children. 2021. Available from: URL: <http://uptodate/contents/midshaft-humeral-fractures-in-children>.
- Von Heideken J, Thiblin I, Högberg U. The epidemiology of infant shaft fractures of femur or humerus by incidence, birth, accidents, and other causes. *BMC Musculoskelet Disord.* 2020; **21**(1): 1-11. [PMID: 33308191]; [PMCID: PMC7731463]; [DOI: 10.1186/s12891-020-03856-4]
- Körner D, Gonser CE, Bahrs C, Hemmann P. Change in paediatric upper extremity fracture incidences in German hospitals from 2002 to 2017: an epidemiological study. *Arch Orthop Trauma Surg [Internet].* 2020; **140**(7): 887-94. [PMID: 31813018]; [DOI: 10.1007/s00402-019-03321-5]
- Mathison DJ, Agrawal D. An Update on the Epidemiology of Pediatric Fractures. *Pediatr Emerg Care.* 2010; **26**(8): 594-603. [PMID: 20693861]; [DOI: 10.1097/PEC.0b013e3181eb838d]
- Hannonen J, Sassi E, Hyvönen H, Sinikumpu JJ. A Shift From Non-operative Care to Surgical Fixation of Pediatric Humeral Shaft Fractures Even Though Their Severity Has Not Changed. *Front Pediatr.* 2020; **8**(November): 1-7. [PMID: 33240832]; [PMCID: PMC7677593]; [DOI: 10.3389/fped.2020.580272]
- Loder RT, Bookout C. Fracture patterns in battered children. Vol. 5, *Journal of Orthopaedic Trauma.* 1991. p. 428-33. [PMID: 1762003]; [DOI: 10.1097/00005131-199112000-00007]
- Kemp AM, Dunstan F, Harrison S, Morris S, Mann M, Rolfe K, *et al.* Patterns of skeletal fractures in child abuse: Systematic review. *Bmj.* 2008; **337**(7674): 859-62. [PMID: 18832412]; [PMCID: PMC2563260]; [DOI: 10.1136/bmj.a1518]
- Leventhal JM, Martin KD, Asnes AG. Incidence of fractures attributable to abuse in young hospitalized children: Results from analysis of a united states database. *Pediatrics.* 2008; **122**(3): 599-604. [PMID: 18762531]; [DOI: 10.1542/peds.2007-1959]
- Leaman LA, Hennrikus WL, Bresnahan JJ. Identifying non-accidental fractures in children aged <2 years. *J Child Orthop.* 2016; **10**(4): 335-41. [PMID: 27339476]; [PMCID: PMC4940250]; [DOI: 10.1007/s11832-016-0755-3]
- Pandya NK, Baldwin KD, Wolfgruber H, Drummond DS, Hosalkar HS. Humerus fractures in the pediatric population: An algorithm to identify abuse. *J Pediatr Orthop Part B.* 2010; **19**(6): 535-41. [PMID: 20606597]; [DOI: 10.1097/BPB.0b013e32833ce424]
- Strait RT, Seigel RM, Shapiro RA. Humeral fractures without obvious etiologies in children less than 3 years of age: when is it abuse? *Pediatrics* 1995; **96**: 667-671. [PMID: 7567328]
- Taitz J, Moran K, O'Meara M. Long bone fractures in children under 3 years of age: Is abuse being missed in Emergency Department presentations? *J Paediatr Child Health.* 2004; **40**(4): 170-4. [PMID: 15009543]; [DOI: 10.1111/j.1440-1754.2004.00332.x]
- Chauvin-Kimoff L, Allard-Dansereau C, Colbourne M. The medical assessment of fractures in suspected child maltreatment: Infants and young children with skeletal injury. *Paediatr Child Heal.* 2018; **23**(2): 156-60. [PMID: 29688229]; [PMCID: PMC5905568]; [DOI: 10.1093/pch/pxx131]
- Bachman D, Santora S. Orthopedic trauma. In: *Textbook of Pediatric Emergency Medicine*, Fleisher GR, Ludwig S, *et al* (Eds), Lippincott Williams & Wilkins, Philadelphia 2006. p.1537.
- Victorian Paediatric Orthopaedic Network. Royal Children's Hospital Melbourne: Humeral Shaft Fractures - Emergency Department. 2020. Available from: URL: https://www.rch.org.au/clinicalguide/guideline_index/fractures/Humeral_shaft_fractures_Emergency_Department/
- Slongo T, Audigé L, AO Pediatric Classification Group (2007) AO Pediatric Comprehensive Classification of Long-Bone Fractures (PCCF). Copyright © 2010 by AO Foundation, Switzerland. Available from: URL: <https://cms.aot-start.org/assets/Uploads/Pediatric-Long-Bone-Fracture-Classification-Brochure.pdf>
- Joeris A, Lutz N, Blumenthal A, Slongo T, Audigé L. The AO Pediatric Comprehensive Classification of Long Bone Fractures (PCCF): Part I: Location and morphology of 2,292 upper extremity fractures in children and adolescents. *Acta Orthop.*

- 2017; **88**(2): 123-8. [PMID: 27882802]; [PMCID: PMC5385104]; [DOI: 10.1080/17453674.2016.1258532]
26. Joeris A, Lutz N, Blumenthal A, Slongo T, Audigé L. The AO Pediatric Comprehensive Classification of Long Bone Fractures (PCCF): Part II: Location and morphology of 548 lower extremity fractures in children and adolescents. *Acta Orthop.* 2017; **88**(2): 129-32. [PMID: 27882811]; [PMCID: PMC5385105]; [DOI: 10.1080/17453674.2016.1258533]
 27. Carson S, Woolridge DP, Colletti J, Kilgore K. Pediatric upper extremity injuries. *Pediatr Clin North Am.* 2006; **53**(1): 41-67. [PMID: 16487784]; [DOI: 10.1016/j.pcl.2005.10.003]
 28. Shah J, Bhatti N. Radial-nerve paralysis associated with fractures of the humerus. A review of 62 cases. *Clin Orthop Relat Res.* 1983; 172: 171-6. [PMID: 6821988]
 29. Oyetunji TA, Haider AH, Downing SR, Bolorunduro OB, Efron DT, Haut ER, Chang DC, Cornwell EE 3rd, Abdullah F, Siram SM: Treatment outcomes of injured children at adult level 1 trauma centers: are there benefits from added specialized care? *Am J Surg* 2011; **201**: 445-9. [PMID: 21421097]; [DOI: 10.1016/j.amjsurg.2010.10.006]
 30. Upasani V. Pediatric Orthopaedic Society of North America (POSNA): Pediatric Polytrauma. 2021. Available from: URL: <https://posna.org/Physician-Education/Study-Guide/Pediatric-Polytrauma>
 31. Pediatric Orthopaedic Society of North America (POSNA) Position Statement the Management of Paediatric Trauma. 2000. Available from: URL: <https://posna.org/POSNA/media/Documents/Position%20Statements/Position-Paper-Final-Trauma-and-Prevention-2000.pdf>
 32. Monsell F, Sepulveda D, Colton C. AO Surgery Reference Pediatric Trauma: Open Fractures in Children. 2016. Available from: URL: <https://surgeryreference.aofoundation.org/orthopedic-trauma/pediatric-trauma/further-reading/open-fractures-in-children>
 33. British Orthopaedic Association & British Association of Plastic, Reconstructive & Aesthetic Surgeons Audit Standards for Trauma: Open Fractures. 2017. Available from: URL: <https://www.boa.ac.uk/uploads/assets/3b91ad0a-9081-4253-92f7d90e8df0fb2c/29bf80f1-1cb6-46b7-afc761119341447f/open%20fractures.pdf>
 34. British Orthopaedic Association & British Association of Plastic, Reconstructive & Aesthetic Surgeons & The Vascular Society for Great Britain and Ireland Audit Standards for Trauma: Diagnosis and Management of arterial injuries associated with extremity fractures and dislocations. 2020. Available from: URL: - <https://www.boa.ac.uk/uploads/assets/febe46fb-f6e0-4663-81494271fde3878c/BOASTArterialInjuries-v2-2020-FINAL.pdf>
 35. Beaty JH. Fractures of the proximal humerus and shaft in children. *Instr Course Lect* 1992; 41: 369-72. [PMID: 1588080]
 36. Zivanovic D V, Slavkovic AR, Radovanovic ZL, Marjanovic ZO. full-textElastic stable intramedullary nailing of humerus fractures in children. *Int J Clin Exp Med [Internet]*. 2018; **11**(4): 2950-2964. Available from: URL: <http://www.ijcem.com/files/ijcem0060170.pdf>
 37. Marengo L, Rousset M, Paonessa M, Vanni S, Dimeglio A, Samba A, *et al.* Displaced humeral shaft fractures in children and adolescents: results and adverse effects in patients treated by elastic stable intramedullary nailing. *Eur J Orthop Surg Traumatol.* 2016; **26**(5): 453-9. [PMID: 26988699]; [DOI: 10.1007/s00590-016-1758-y]
 38. Asche G. Use of external fixation in pediatric fractures. *Zentralbl Chir* 1986; 111: 391-7. [PMID: 3716669]
 39. Lieber J, Schmittenebecher P. Developments in the treatment of pediatric long bone shaft fractures. *Eur J Pediatr Surg.* 2013; **23**(6): 427-33. [PMID: 24327219]; [DOI: 10.1055/s-0033-1360460]
 40. Kosuge D, Barry M. Changing trends in the management of children's fractures. *Bone Joint J.* 2015; 97-B (4): 442-8. [PMID: 25820880]; [DOI: 10.1302/0301-620X.97B4.34723]
 41. Fernandez FF, Eberhardt O, Wirth T. Elastic stable intramedullary nailing as alternative therapy for the management of paediatric humeral shaft fractures. *Z Orthop Unfall* 2010; **148**(1): 49-53. [PMID: 20135597]; [DOI: 10.1055/s-0029-1186113]
 42. Pogorelič Z, Kadić S, Milunović KP, Pintarić I, Jukić M, Furlan D. Flexible intramedullary nailing for treatment of proximal humeral and humeral shaft fractures in children: A retrospective series of 118 cases. *Orthop Traumatol Surg Res.* 2017; **103**(5): 765-70. [PMID: 28330797]; [DOI: 10.1016/j.otsr.2017.02.007]
 43. Canavese F, Marengo L, Cravino M, Giacometti V, Pereira B, DiMeglio A, *et al.* Outcome of Conservative Versus Surgical Treatment of Humeral Shaft Fracture in Children and Adolescents: Comparison between Nonoperative Treatment (Desault's Bandage), External Fixation and Elastic Stable Intramedullary Nailing. *J Pediatr Orthop.* 2017; **37**(3): e156-63. [PMID: 27479190]; [DOI: 10.1097/BPO.0000000000000843]
 44. Garg S, Dobbs MB, Schoenecker PL, Luhmann SJ, Gordon JE. Surgical treatment of traumatic pediatric humeral diaphyseal fractures with titanium elastic nails. *J Child Orthop.* 2009; **3**(2): 121-7. [PMID: 19308623]; [PMCID: PMC2656946]; [DOI: 10.1007/s11832-009-0166-9]
 45. Abosalim AE-A, El-Din AS, El-Mowafy H. Treatment of humeral shaft fractures by a single elastic stable intramedullary nail in children. *Menoufia Med J.* 2015; **28**(1): 125. [DOI: 10.4103/1110-2098.155967]
 46. Kwak YH, Min SK, Lee YB PK. Operative Treatment of Pediatric Humeral Diaphyseal Fractures with Flexible Intramedullary Nails. *J Korean Orthop Assoc.* 2012; **47**: 250-6. [DOI: 10.4055/jkoa.2012.47.4.250]
 47. Kelly DM. Flexible intramedullary nailing of pediatric humeral fractures: Indications, techniques, and tips. *J Pediatr Orthop.* 2016; **36**(4): S49-55. [PMID: 27152902]; [DOI: 10.1097/BPO.0000000000000755]