



The utility of mini C-arm in the fixation of unstable paediatric supracondylar humeral fractures



Zong Xian Li^{a,*}, Kenneth Pak Leung Wong^a, Jeannie Leh Ying Wong^b,
Kevin Boon Leong Lim^a, Arjandas Mahadev^a

^a Department of Orthopedic Surgery, KK Women's and Children's Hospital, Singapore

^b National University of Singapore, Singapore

ARTICLE INFO

Article history:

Accepted 8 September 2019

Keywords:

Paediatric fractures
Humerus supracondylar fractures
Radiation exposure
Image intensifier
Fluoroscopy
Percutaneous fixation
Mini C-arm
Radiation safety
Quality improvement
Upper limb

ABSTRACT

Background: Pediatric supracondylar humerus fractures have traditionally been reduced and fixed with conventional C-arm (CCA) fluoroscopy guidance. With the increase in popularity of the newer mini C-arm (MCA) system within other fields of surgery due to its ease of use and lower radiation emission, the same adoption should be explored in pediatric orthopedic surgeries. The purpose of this study is to compare the MCA and CCA primarily in reduction and fixation outcomes and secondarily in other perioperative parameters.

Methods: Retrospective analysis of 193 patients who underwent surgical fixation for displaced supracondylar humerus fractures. 44 and 149 cases were performed with the MCA and CCA respectively. Baumann's angle and the intersection of anterior humeral line (AHL) were assessed on postoperative anterior posterior and lateral radiographs and adequate reduction was defined by an angle between 64 and 81°, and AHL intersecting middle third of the capitellum. Surgical time, fluoroscopy duration, number of images and radiation exposure were obtained from the surgical notes.

Results: Amongst the CCA cases, there were greater satisfactory coronal plane reduction ($p < 0.05$), while no difference in sagittal plane accuracy ($p > 0.05$) was seen. In MCA group, longer surgical ($p < 0.05$) and fluoroscopy times ($p < 0.05$), and greater number of shots ($p < 0.05$) was noted. However overall radiation exposure in the MCA group was still lower ($p < 0.05$).

Conclusion: The MCA system is potentially less accurate in coronal plane reduction and more challenging to use. However, pitfalls can easily be avoided. Usage should be advocated as overall radiation exposure can be reduced.

Level of evidence: Level III retrospective comparative study.

© 2019 Elsevier Ltd. All rights reserved.

Introduction

Pediatric supracondylar humeral fracture (SHF) is the most common elbow fracture in children, the second most common fracture in childhood (3–16.6%) and the most common fracture before the age of seven [1–4]. They are known to result in malunion, neurovascular complications and compartment syndrome [5,6].

Many methods of reduction and fixation have been described, ranging from conservative traction, closed reduction and percutaneous K-wire fixation, descending elastic stable intramedullary nailing, to radial external fixator [7–10]. However, the current

standard of care and preferred method in our institution would be of closed reduction and percutaneous fixation with unburred K-wires. This fixation method can help avoid the complications of an open procedure, and of a second general anesthesia encounter for implant removal [11–13]. This minimally invasive, closed procedure must be performed under image guidance, traditionally from a conventional C-arm fluoroscopy (CCA), to display real-time images of the skeletal anatomy [14].

Despite the advantages and benefits of fluoroscopic guidance, iatrogenic radiation exposure to both the patient and surgeon remains a concern as evidence from longitudinal studies of atomic bomb survivors in Japan suggest a significant increase in the lifetime risk of radiation induced malignancies, especially in the pediatric patient [15–17].

The mini C-arm (MCA) has been promoted in recent years with claims of reducing radiation emission and scatter [18]. It has been reported that the MCA reduces radiation exposure to the patient

* Corresponding author at: KK Women's and Children's Hospital, 100 Bukit Timah Road, 229899, Singapore.

E-mail address: Zongxian.li@mohh.com.sg (Z.X. Li).

and surgeon by a factor of 10 compared with the conventional big C-arm intensifier [19]. The tighter collimation and smaller C-arm circumferences aids in reducing exposure and radiation dosage. With the smaller circumference, the MCA is intuitively more suited for peripheral surgeries in the adult population, as it can be difficult to image proximal to the elbow or distal tibia. Thus, it comes as no surprise the rapid adoption of MCA usage amongst the hand, and foot and ankle community.

With the abovementioned, there seems to be no reason why the MCA should not be adopted for use with pediatric supracondylar fixations as well. The reduced radiation would be additionally beneficial to the pediatric patient, while the smaller circumference of the MCA should not be an issue with the smaller size and arm girth of these patients.

The purpose of this study is to show the adequacy and suitability of the MCA as an intraoperative image guidance tool as compared with the traditional CCA. We will be comparing the operative parameters and outcomes of SHF fixation using the MCA versus the CCA in our hospital.

Materials and methods

This was a retrospective chart and radiographic review of all pediatric SHF that underwent surgical fixation in our hospital over a 2-year period. Patients who had more than one fracture that were fixed concurrently were excluded from the study. A total of 193 patients met our selection criteria.

Patient details were obtained from their individual hospital case notes, electronic documentation records and operating theatre register. The type of C-arm fluoroscopy used intraoperatively was at the discretion of the individual surgeon and clinical details were recorded by the managing surgical team upon the patient's presentation. The MCA and CCA systems we use in our institution are the Ziehm Imaging OrthoScan FD-OR and Ziehm Imaging Ziehm Vision respectively.

Positioning of the CCA machine during supracondylar fracture fixation has traditionally been described with the drum placed inferiorly with the emitter superiorly, directed downwards. The drum thus functions akin to a surgical table where the limb is positioned and rested upon during shots [20]. In our institution, the MCA was used in a similar manner, as shown in Fig. 1, with the

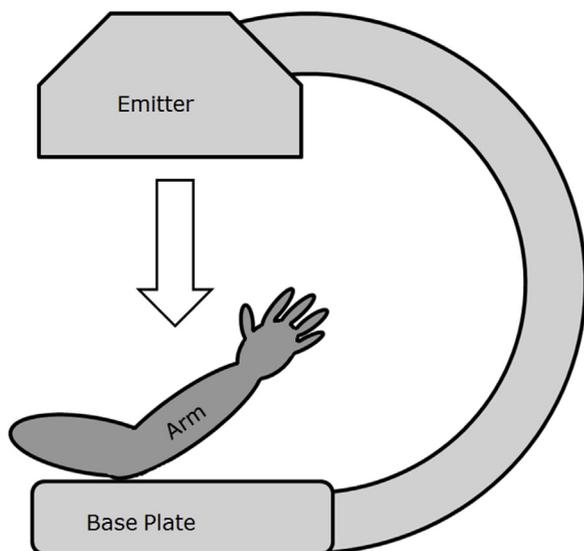


Fig. 1. Intra operative positioning of the MCA. The base plate is positioned under the elbow with the long axis in line with the arm, functioning like an operating table, with the emitter directed downwards from above.

base plate positioned inferiorly as a “table” for the elbow and the emitter superiorly directed downwards. The use of a separate hand table beneath the base plate was optional.

All patients underwent close reduction intra operatively under general anaesthesia and were fixed with percutaneous 1.6 mm Kirschner wires in the usual fashion in accordance with the American Academy of Orthopaedic Surgeon guidelines [21].

The fractures were classified according to the Gartland classification [22,23] and postoperative anteroposterior and lateral radiographs were reviewed for adequacy of reduction.

On the anteroposterior radiograph, the Baumann's angle, described by the angulation between a line drawn through the longitudinal axis of the humerus and a line drawn between the lateral condylar physis and the distal humeral epiphysis, is measured as shown in Fig. 2, and an angle between 64° to 81° is recorded as having a satisfactory coronal reduction [24,25]. While on the lateral radiograph, the “anterior humeral line” is drawn as per Fig. 3, described as the sagittal alignment, where a line drawn along the anterior border of the distal humeral shaft, extending distally to intersect with the capitellum ossification center. A satisfactory sagittal reduction has been achieved when the anterior humeral line intersects the middle third of the capitellum ossification centre [26].

Total surgical time, type of c-arm fluoroscopy, fluoroscopy duration in seconds, the number of fluoroscopy images and radiation exposure to the patient were obtained from the surgical records and radiograph machines as well.

Statistical analyses were performed using the Analysis ToolPak, a Microsoft Excel add-in program. Two-proportion z-tests were performed to decide if the differences between the Anterior Humeral accuracy rates of the mini II and conventional II machines are significant. Meanwhile F-tests were conducted to identify significant differences in variances between the number of shots, II duration, surgical duration, radiation dose, and Baumann's angle for cases using the Mini II machine versus the convention II machine; then t-tests were performed to identify significant differences in means. A *p* value of <0.05 was taken as statistically significant.

Approval was obtained from the hospital institutional review board prior to the onset of the study and no external sources of funding was involved for the study.

Results

On hundred and ninety-three patients with displaced SHF who underwent closed reduction and percutaneous pinning over the 2-year period met our selection criteria. The mean age was 7.9 years (2.0–16.0 years) with a male to female ratio of 107:86. The mean operative time was 20.7 min (4.0–69.1 min), and Gartland grade 2B to 3 ratio of 32:161. The mean post-operative Baumann's angle was 70° (52.1 – 86.3°), with satisfactory coronal reduction in 79.8% and sagittal reduction in 51.8% of the cases. The average number of fluoroscopy images taken was 31.3 (6–107) with average fluoroscopy time of 30 s (3–244 s).

Surgical fixation was performed with MCA imaging in 44 patients and CCA imaging in 149 patients. Table 1 compares the study parameters between the 2 groups.

There were no statistically significant differences in both groups in terms of age, gender distribution or Gartland grading. It was found that for the cases performed under MCA imaging, there was a statistically significant lower rate of satisfactory coronal plane reduction (68.2% vs. 83.2%, $p=0.029$), however, the mean Baumann's angles were not statistically different (68.6° vs. 70.5° , $p=0.130$). There were also no differences in sagittal plane reduction accuracy (50.0% vs. 52.4%, $p=0.784$). Surgical parameters wise, the MCA group had a statistically significant longer operative



Fig. 2. Baumann's angle; the angulation on the anteroposterior radiograph between a line drawn through the longitudinal axis of the humerus and a line drawn between the lateral condylar physis and the distal humeral epiphysis. Pre and post reduction images as shown.

duration (27.4 vs. 18.7 min, $p = 0.000$), longer fluoroscopy exposure (52.6 vs. 25.3s, $p = 0.08$) and a greater number of fluoroscopy shots taken (40.8 vs. 29.4, $p = 0.043$). Despite so, the overall radiation exposure to the patient in the MCA group was still much lesser compared to the CCA group (0.4 vs. 6.8 mGy.cm², $p = 0.000$).

Discussion

In the fixation of pediatric supracondylar humeral fractures, fluoroscopic image guidance is indispensable in ensuring adequate fracture reduction and accurate percutaneous pin placement to achieve optimal surgical outcomes.

This is the first study to examine the utility of an MCA system in the fixation of pediatric supracondylar fractures and compare the outcomes with fixations performed using the CCA system.

In our study population of 193 patients, 44 and 149 patients underwent fixation with the MCA and CCA image intensifiers respectively. Both groups were comparable in terms of age, gender distribution and Gartland grading. Our average operative time of 18.7 min (range, 4–59.2 min) also compares favorably with reported timings of 20–35 min [27,28].

It was found that despite having statistically similar mean Baumann's angles, the proportion of satisfactorily reduced coronal alignments was significantly greater in the CCA group. The distribution of Baumann's angles in the CCA group appears to be narrower with a smaller standard deviation compared with the MCA group (5.9° vs 7.5°). This suggests that the MCA fixations were less accurate with a greater proportion of outliers outside the ideal 64° to 81° range. However, a similar effect was not seen in the accuracy of the sagittal plane reductions. The accuracy of the sagittal plane alignments was comparable between both the MCA and CCA groups with no statistically significant differences.

In a separate survey conducted amongst the attending surgeons and residents in the department, it was found that the CCA and MCA images could only be correctly differentiated less than half of the time. This seems to suggest that the disparity of fixation accuracy in the coronal plane between the two systems was independent of the quality or resolution of the images produced. We postulate that the smaller field of the MCA may have excluded more of the humeral shaft compared with the CCA, making the assessment and estimation of the Baumann's angle intra operatively less accurate. To achieve accurate representation of the Baumann's angle, the long axis of the humerus should be referenced off the diaphyseal region in the humeral shaft as shown in Fig. 1. Referencing off the flared metaphyseal region of the distal humerus would give a poorer gauge of the true long axis. This did not seem to be an issue with the intra operative assessment of the sagittal alignment as the anterior humeral line can easily and accurately be drawn off the anterior cortex of the distal humerus without need for visualization of the whole shaft, as can be seen in Fig. 2.

It was also found that the MCA group had a significantly longer surgical time, greater number of fluoroscopy images taken, and longer fluoroscopy time. This, we believe, can be accounted to three main reasons. Firstly, the smaller field of vision of the MCA and longer acquisition time required to produce a clear image meant that there are more exposures taken that do not produce clinically useful images, with partial imaging of the elbow due to mispositioning, or blurred images due to motion artefacts. This would necessitate repeated fluoroscopy shots each time to obtain the images intended. A similar conclusion was drawn by Shoab et al in an earlier study which reported significantly larger number of exposures with the mini C-arm during orthopedic extremity surgeries. [29] Secondly, the usage of the MCA in supracondylar fracture fixations have only been recently introduced in our

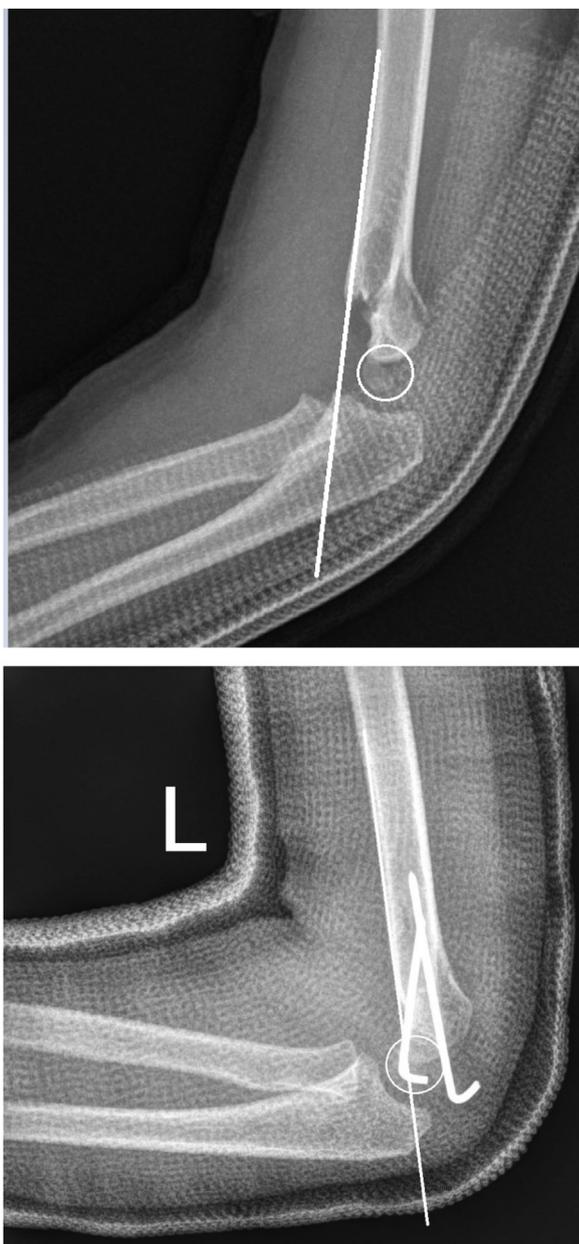


Fig. 3. Anterior Humeral Line; a line drawn along the anterior border of the distal humeral shaft on the lateral radiograph, extending distally to intersect with the capitellum ossification center. This line should pass through the middle third of the ossification center. Pre and post reduction images as shown.

Table 1
Comparison of the MCA and CCA group of patients.

	MCA	CCA	p value
N	44	149	–
Age (years)	7.4	8.1	0.157
Males	21 (47.7%)	86 (57.7%)	0.244
Operative time (min)	27.4	18.7	0.000*
Gartland 2B	8 (18.2%)	24 (16.1%)	0.701
Baumann's angle (°)	68.6	70.5	0.130
Satisfactory coronal reduction	30 (68.2%)	124 (83.2%)	0.029*
Satisfactory sagittal reduction	22 (50.0%)	78 (52.4%)	0.784
Number of fluoroscopy shots	40.8	29.4	0.043*
Fluoroscopy duration (sec)	52.6	25.3	0.008*
DAP (mGy.cm ²)	0.4	6.8	0.000*

* Denotes statistically significant difference between groups. SD, standard deviation; DAP, dose area product.

institution. This could have created an initial learning curve as the surgeons would not be as familiar in the positioning and targeting of the MCA image intensifier as compared with the CCA intensifier which has been used all along before this. Thirdly, as mentioned above, the CCA drum has traditionally been used as a makeshift surgical table. With the MCA base plate being used instead, it proved to be a less stable platform which was prone to shifting when encountered with excessive weight or force. This required readjustment of the base plate and would further complicate the targeting for subsequent fluoroscopy shots.

However, despite the longer fluoroscopy duration and greater number of shots taken in the MCA group, the tighter collimation and smaller distance between the source and base plate of the MCA proved much more advantageous in reducing overall radiation exposure to the patient. With the MCA, the total dose area product measured, which indicates the radiation absorbed by the irradiated tissue, shown a 17-fold decrease as compared with the CCA. We can further extrapolate from this that the radiation exposure to the surgeon is also decreased in the same manner.

The strength of the study would be the large number of patients in both arms of the comparison. We are the largest pediatric department in the country and represent the majority of all supracondylar fractures encountered and operated on. As we are a teaching hospital, cases from both arms were performed both by attending surgeons as well as residents, with a good spread of surgical experience. This heterogeneity makes our findings more applicable to other tertiary or teaching hospitals.

This paper presents interesting data in the intraoperative fixation of pediatric supracondylar humerus fractures. However, there are potential weaknesses in the study that can be improved. Firstly, even though the MCA had been available prior to the start of the study, its usage during supracondylar fracture fixation was only recently adopted. This initial learning curve may have accounted for the large disparity of surgical parameters like surgical and fluoroscopy time. Secondly, as this is a retrospective study and the decision to use either MCA or CCA falls on the discretion of the operating surgeon, we are unable to claim that distribution of patients in each arm are truly random. For this reason, further prospective studies with formal randomization, which would equalize any potential differences between the study and control group, should be conducted.

Furthermore, for the current study, we looked at the quality of fracture reductions for extra articular fractures where perfect anatomical reduction was not as crucial. We may not be able to extrapolate the findings and conclusions to other elbow fractures that are intra-articular, like lateral condyle fractures. Being intra-articular, a more accurate and perfect anatomical reduction is necessary to avoid articular incongruity and onset of post traumatic osteoarthritis. As such, the lower imaging resolution of the MCA may prove to be insufficient when compared with the CCA.

It is the recommendation of the author that while using the mini C-arm, care must be taken to ensure adequate fluoroscopic visualization of the humeral shaft during reduction to allow proper assessment of coronal and sagittal alignment. As the field of exposure of the mini C-arm is rectangular, in contrast to the circular drum of the conventional C-arm, the image intensifier base plate should be positioned with the long axis in line with the humerus shaft and perpendicular to the body, as shown in Fig. 3. This would enable adequate visualization of both the elbow and humeral shaft in the same exposure. Targeting of the mini C-arm can be challenging, but inaccurate exposures can be mitigated by the following methods: calibrate and mark out the actual mini C-arm field of exposure on the base plate such that it can still be visible after donning the transparent plastic sterile drapes; usage of the built-in laser targeting system to help frame the exposure; stabilize the base plate and elbow with support from a rigid and locked hand table placed beneath.

With the above methods, one should be able to achieve optimal assessment of the reduction alignment, minimize the number of non-useful fluoroscopic exposures, and decrease overall fluoroscopic and surgical time.

The usage of a mini C-arm fluoroscopy system in the fixation of unstable supracondylar fractures may prove to be less accurate in the coronal alignment with a marginally greater proportion of outliers, and technically more challenging with longer operative durations and fluoroscopy usage. However, along with more experience, when one is aware of the possible weaknesses and potential pitfalls during its usage, they can easily be mitigated. We would still strongly recommend for it as overall radiation exposure to both the patient and surgeon can be greatly reduced.

Take home message:

- A mini C-arm fluoroscopy system is a viable alternative imaging system for the fixation of supracondylar fractures
- Resultant reduction in radiation exposure will prove beneficial to both patient and surgeon.

Declaration of Competing Interest

The authors of the manuscript confirm that there are no financial or personal conflicts of interest with other people or organisation that could inappropriately influence our work.

References

- [1] Wegmann H, Orendi I, Singer G, Eberl R, Castellani C, Schalamon J, et al. The epidemiology of fractures in infants: which accidents are preventable? *Injury* 2016;47:188–91.
- [2] Khoshbin A, Leroux T, Wasserstein D, Wolfstadt J, Law PW, Mahomed N, et al. The epidemiology of paediatric supracondylar fracture fixation: a population-based study. *Injury* 2014;45:701–8.
- [3] Mulpuri K, Hosalkar H, Howard A. AAOS clinical practice guideline: the treatment of pediatric supracondylar humerus fractures. *J Am Acad Orthop Surg* 2012;20:328–30.
- [4] Cheng JC, Shen WY. Limb fracture pattern in different pediatric age groups: a study of 3350 children. *J Orthop Trauma* 1993;7(1):15–22.
- [5] Hanlon CR, Estes Jr. WL. Fractures in childhood, a statistical analysis. *Am J Surg* 1954;87(3):312–23.
- [6] Arnold JA, Nasca RJ, Nelson CL. Supracondylar fractures of the humerus: the role of dynamic factors in prevention of deformity. *J Bone Joint Surg Am* 1977;59(5):589–95.
- [7] Piggot J, Graham HK, McCoy GF. Supracondylar fractures of the humerus in children. Treatment by straight lateral traction. *J Bone Jt Surg Br* 1986;68(577):e83.
- [8] Kim WY, Chandru R, Bonshahi A, Paton RW. Displaced supracondylar humeral fractures in children: results of a national survey of paediatric orthopaedic consultants. *Injury* 2003;34(274):e7.
- [9] Pretell-Mazzini J, Rodriguez-Martin J, Auñon-Martin I, Zafra-Jimenez AA. Controversial topics in the management of displaced supracondylar humerus fractures in children. *Strategies Trauma Limb Reconstr* 2011;6:43–50.
- [10] Prévot J, Lascombes P, Métaizeau JP, Blanquart D. Supracondylar fractures of the humerus in children: treatment by downward nailing. *Rev Chir Orthop* 1990;76:191–7.
- [11] Diri B, Tomak Y, Karaismailoglu TN. The treatment of displaced supracondylar fractures of the humerus in children (an evaluation of three different treatment methods). *Ulus Travma Acil Cerrahi Derg* 2003;9(1):62–9.
- [12] Bombaci H, Gereli A, Kucukyazici O, Gorgec M, Deniz G. The effect of surgical exposure on the clinic outcomes of supracondylar humerus fractures in children. *Ulus Travma Acil Cerrahi Derg* 2007;13(1):49–54.
- [13] Iobst CA, Spurdle C, King WF, Lopez M. Percutaneous pinning of pediatric supracondylar humerus fractures with the semisterile technique: the Miami experience. *J Pediatr Orthop* 2007;27(1):17–22.
- [14] Giordano BD, Ryder S, Baumhauer JF, DiGiovanni BF. Exposure to direct and scatter radiation with use of mini C-arm fluoroscopy. *J Bone Joint Surg Am* 2007;89:948–52.
- [15] Pierce DA, Preston DL. Radiation-related cancer risks at low doses among atomic bomb survivors. *Radiat Res* 2000;154:178–86.
- [16] Pierce DA, Vaeth M. Age-time distribution of cancer risks to be expected from acute or chronic exposures to general mutagens. *Radiat Res* 2000;154:727–8.
- [17] Preston DL, Ron E, Tokuoka S, Funamoto S, Nishi N, Soda M, et al. Solid cancer incidence in atomic bomb survivors: 1958–1998. *Radiat Res* 2007;168:1–64.
- [18] Badman B, Rill L, Butkovich B, Arreola M, Griend R. Radiation exposure with use of the mini C-arm for routine orthopaedic imaging procedures. *J Bone Joint Surg Am* 2005;87:13–7.
- [19] Singer G. Occupational radiation exposure to the surgeon. *J Am Acad Orthop Surg* 2005;13:69–76.
- [20] Hsu RY, Lareau CR, Kim JS, Korupolu S, Born CT, Schiller JR. The effect of C-arm position on radiation exposure during fixation of pediatric supracondylar fractures of the humerus. *J Bone Joint Surg Am* 2014;96(1–6):e129.
- [21] American Academy of Orthopaedic Surgeons. The treatment of pediatric supracondylar humerus fractures. Evidence-based guideline and evidence report. Retrieved from. 2011. https://www.aaos.org/uploadedFiles/PreProduction/Quality/Guidelines_and_Reviews/PSHF_CPG_10.31.16.pdf.
- [22] Gartland JJ. Management of supracondylar fractures of the humerus in children. *Surg Gynecol Obstet* 1959;109(2):145–54.
- [23] Wilkins K. Fractures and dislocations of the elbow region. In: Rockwood CA, Wilkins K, King R, editors. *Fractures in children*. 3rd ed. Philadelphia: JB Lipincott Co.; 1991. p. 509–828.
- [24] Worlock P. Supracondylar fractures of the humerus: assessment of cubitus varus by the Baumann angle. *J Bone Joint Surg Br* 1986;68:755–7.
- [25] Williamson DM, Coates CJ, Miller RK, Cole WG. Normal characteristics of the Baumann (humero-capitellar) angle: an aid in assessment of supracondylar fractures. *J Pediatr Orthop* 1992;12(5):636–9.
- [26] Silberstein MJ, Brodeur AE, Graviss ER, Atchawee L. Some vagaries of the capitellum. *J Bone Joint Surg Am* 1981;63:524–8.
- [27] Donnelly M, Green C, Kelly IP. An inconvenient truth: treatment of displaced paediatric supracondylar humeral fractures. *Surgeon* 2012;10:143–7.
- [28] Liu RW, Roocroft J, Bastrom T, Yaszay B. Surgeon learning curve for pediatric supracondylar humerus fractures. *J Pediatr Orthop* 2011;31:818–24.
- [29] Shoaib A, Rethnam U, Bansal R, De A, Makwana N. A comparison of radiation exposure with the conventional versus mini C arm in orthopedic extremity surgery. *Foot Ankle Int* 2008;29:58–61.