

## Does radiation exposure during pediatric supracondylar humeral fracture surgery change according to the C-arm position? A comparison of two different techniques

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### ABSTRACT

**Introduction:** In the surgical treatment of supracondylar humeral fractures (SHF), the surgeon has to stand right next to the fluoroscopy device, so it is very important to know how to use it in the most appropriate way to reduce radiation exposure. The aim of this study was to investigate the effect of using C-arm in uniplanar (inverted) and biplanar (standard-horizontal) configurations on (1) the radiation exposure to the surgeon, and (2) surgical time and fluoroscopy exposure time.

**Material and methods:** This prospective randomised study was conducted on 20 patients who underwent fluoroscopy during closed reduction and percutaneous pinning for a SHF. In the first configuration, the C-arm was inverted and the image intensifier was used as a surgical table. In the second configuration, the C-arm was used biplanar. The operations were performed by 5 surgeons, with each surgeon using each method only twice. During the operation, to find a value closed to direct radiation exposure measurement was made by attaching a dosimeter to the wrist and scatter radiation exposure was measured by attaching a dosimeter to the neck and waist of the surgeons. The operation time and fluoroscopy exposure time were determined.

**Results:** The duration of operations performed with the biplanar C-arm position and the fluoroscopy exposure time in operations performed with the uniplanar method were found to be statistically significantly longer ( $p = 0.001$ ). The measurements on the dosimeter worn on the neck of surgeons were found to be statistically significantly higher while using the uniplanar C-arm configuration ( $p = 0.001$ ). There was no statistically significant difference between the dosimeter measurements on the wrists and waists of the surgeons and the C-arm configurations ( $p = 0.820$ ;  $p = 0.185$ ).

**Conclusions:** Although the use of biplanar C-arm has no effect on radiation exposure to the surgeon's wrist, the most important advantages are that the neck area is exposed to less radiation and it shortens the fluoroscopy time so the use of a biplanar C-arm can be recommended.

**Level of evidence:** Level II

### Introduction

Pediatric supracondylar humeral fractures (SHF) are the most common elbow fractures and have the most common surgical indication in children [1]. SHFs account for one-third of all fractures diagnosed in children younger than 8 years of age and one-quarter of all pediatric orthopedic surgical procedures [2]. The Wilkins modification of the Gartland classification system is commonly used to classify

extension-type fractures. According to the Gartland classification, the generally accepted treatment for displaced type 2 and type 3 fractures is closed reduction and percutaneous pinning [3–5].

Fluoroscopy is necessary to determine the adequacy of reduction and fixation in the surgical treatment of these very common fractures. Despite all the benefits of using fluoroscopy, exposure of patients and the surgical team to iatrogenic radiation is a concern among surgeons. During fluoroscopy use, radiation can scatter in all directions from the x-

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ray tube so this causes exposure to scattered radiation however during imaging, the surgeon’s hands often pass through the radiation beam, which leads to direct radiation exposure [6]. Previous studies have shown that exposure to ionized radiation increases the risk of lifelong cancer development [7–9]. Therefore, many studies have investigated the radiation exposure associated with the use of fluoroscopy in various orthopedic surgical procedures [6,10–12]. Radiation exposure decreases with distance from fluoroscopy [6] but even with current surgical techniques, in the surgical treatment of SHFs, the surgeon has to stand right next to the fluoroscope during most of the intraoperative imaging, so it is very important to know how to use the device in the most appropriate way to reduce radiation exposure.

The aim of this study was to investigate the effect of using 2 different C-arm configurations for reduction and fixation of type 3 SHFs on radiation exposure to the wrist, waist and neck region of the surgeon, on the fluoroscopy exposure time and the surgical time. The study hypothesis was that the C-arm position would have no effect on radiation exposure to the wrist, but scatter radiation exposure to the neck region would be different when the C-arm is in the uniplanar (inverted) position compared to the biplanar position.

**Material and method**

*Patient selection and study design*

This prospective randomised, single-center study was conducted on

20 patients, comprising 13 males and 7 females with an average age of  $6.70 \pm 1.71$  years (range, 4 to 10 years) who underwent fluoroscopy during closed reduction and percutaneous pinning for a supracondylar humeral fracture between January and August 2022 (Fig. 1). Approval for the study was granted by the Institutional Review Board. Informed consent was provided by all the parents/legal guardians of the patients. The study was conducted in accordance with the principles of the Helsinki Declaration.

The study inclusion criteria were as follows:

- (1) Patient age between 3 and 14 years.
- (2) Patients undergoing closed reduction and percutaneous pinning.
- (3) Gartland type 3 supracondylar humerus fracture [3].
- (4) Typical fracture patterns according to the Johns Hopkins fracture classification [13].
- (5) Acute and closed fractures.
- (6) Patients with isolated unilateral supracondylar humerus fractures.
- (7) Fractures with fixation using 2 lateral and 1 medial pins.

The study exclusion criteria were defined as age < 3 years or >14 years, fracture types different from Gartland type 3 and typical fracture, patients undergoing open reduction and fixation, patients with ipsilateral upper extremity fractures, and patients on whom different pin configurations had to be used.

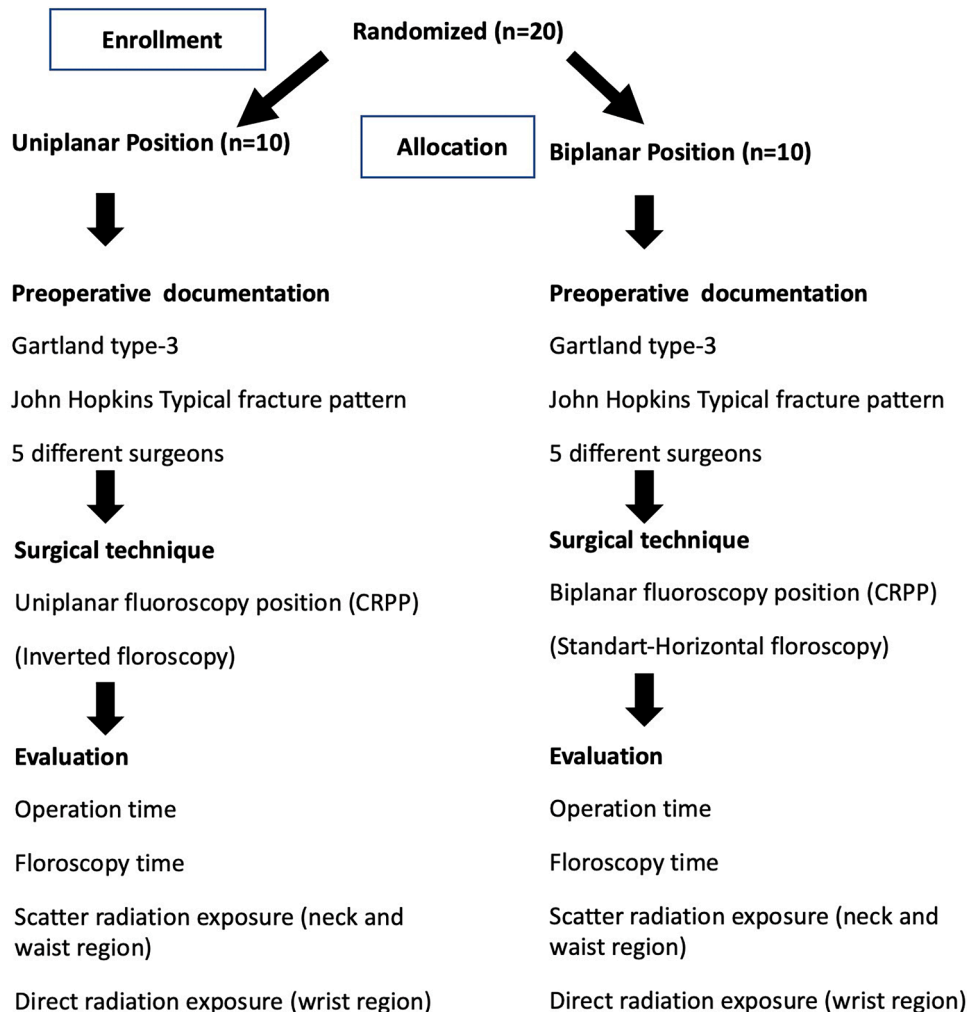


Fig. 1. CONSORT (Consolidated Standards of Reporting Trials) flow diagram.

### Surgical technique

All surgeries were performed under fluoroscopy control, in the supine position and under general anesthesia. A lead shield was placed over the patients to minimize radiation exposure during the surgery. The surgeries were performed with two different C-arm configurations.

**Technique 1:** In the initial configuration, the C-arm was uniplanarly inverted, so the image intensifier was on the floor and the x-ray tube was on the ceiling. In this configuration, the image intensifier was used as the operating table (Fig. 2). In this position, the upper extremity was rotated for antero-posterior (AP) and lateral elbow imaging while the C-arm was in the fixed position.

**Technique 2:** In the second configuration, the C-arm was used biplanar. With the elbow on the radiolucent hand table, the fluoroscopy position was initially adjusted with the x-ray tube on the floor and the image intensifier on the ceiling, and closed reduction of the elbow was performed in the antero-posterior plane, and the elbow AP-view was evaluated. For lateral imaging, while the surgeon kept the patient's arm in the reduced position, the fluoroscopy device was rotated 90° and reduction was evaluated laterally. The same procedure was repeated during fixation after proper reduction was achieved in both planes. During the operation, the patient's arm was not rotated for lateral imaging, so the elbow was kept in the fixed position (Fig. 3).

In all operations, closed reduction was achieved in both planes, primarily after AP and lateral imaging. After the reduction, bicolunar, double cortex fixation was performed with crossed 2 lateral and 1 medial K-wires applied to all patients as standard [14]. After confirming that the fixation was stable and the reduction was appropriate, the surgery was finished. The reduction criteria were Bauman angle in the coronal plane, mid-third of the anterior humeral line in the sagittal plane, and Gordon rotation index in the axial plane [15–17]. The surgeries were performed by 5 senior surgeons experienced in both techniques.

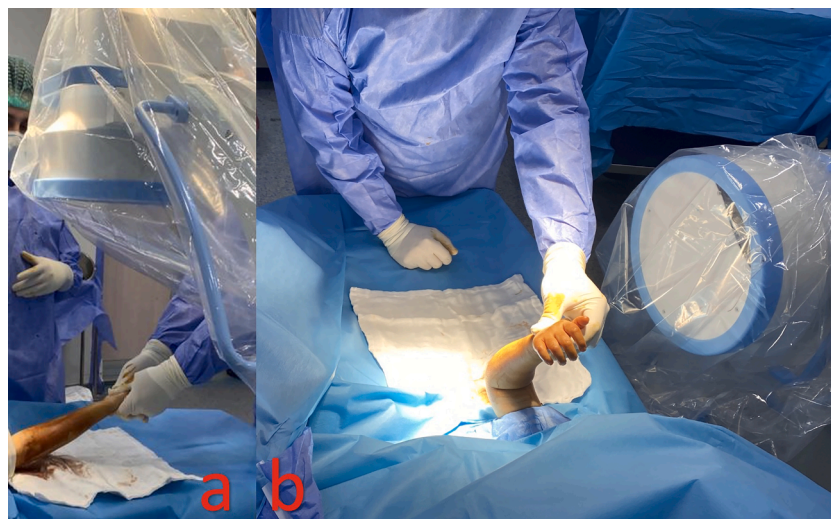
Each surgeon performed 4 surgeries, two in each of the two different C-arm configurations. The same resident surgeon assisted in all surgeries. The C-arm configuration of the operation was determined according to the coin flip method. During surgery, scatter radiation exposure was measured by attaching a dosimeter (OSL dosimeter Landauer InLight – LDR Model 2 OSL, Istanbul, Turkey) to the neck and waist of the surgeons. However, since the wrist was constantly moving, the amount of direct radiation exposure could not be measured exactly. An approximate value was tried to be measured by attaching a dosimeter to the dominant wrist of surgeons. During the operations, the surgeons used all necessary protective equipment including a lead shield, thyroid shield, and lead-lined eye protection. Radiation measurements were made by attaching the dosimeters to the outer part of the lead shield. The operation time was determined as the time between the first and the last fluoroscopy shot and was recorded. Fluoroscopy exposure time is the active working time of fluoroscopy and is directly related to the number of shots. This time is automatically recorded by the device. All surgeries were performed using the same fluoroscopy device in the presence of the same fluoroscopy technician, and the fluoroscopy exposure time was recorded (INFINIX, Toshiba ©, Otawara, Japan). A standard laser was used for aiming to reduce missed scans which would require additional radiation exposure.

### Statistical analysis

Data obtained in the study were analyzed statistically using NCSS (Number Cruncher Statistical System) 2020 software (Kaysville, Utah, USA). While evaluating the study data, quantitative variables were reported as mean, standard deviation, median, minimum and maximum values, and qualitative variables were shown with descriptive statistical methods as frequency and percentage. The Shapiro Wilks test and Box Plot graphics were used to evaluate the conformity of the data to normal distribution. The Mann-Whitney-U test was used in the comparisons of



Fig. 2. Inverted C-arm positioning using the image intensifier as the operating table. Elbow AP imaging (a). Elbow rotated externally 90° for lateral imaging (b).



**Fig. 3.** Biplanar C-arm configuration. C-arm in standard position for elbow AP imaging (a). For lateral imaging, the C-arm is in the horizontal position with the elbow in the fixed position (b).

two groups of non-normally distributed variables. The results were evaluated in a 95% confidence interval and at the significance level of  $p < 0.05$ . In the selected sample, power was 95%, and alpha was 0.01.

## Results

There was no statistically difference between the C-arm configurations and the gender and age of the cases ( $p = 1.000$ ;  $p = 0.538$ ) (Table 1).

The duration of operations performed with the biplanar C-arm position was found to be statistically significantly longer than those performed with the uniplanar position ( $40,80 \pm 5,94$  min;  $29,00 \pm 6,83$  min) ( $p = 0.001$ ) (Fig. 4) (Table 1).

The fluoroscopy exposure time in operations performed with the uniplanar method was found to be statistically significantly longer than the operations performed with the biplanar method ( $47,50 \pm 6,74$  s;  $27,70 \pm 9,25$  s) ( $p = 0.001$ ) (Fig. 4) (Table 1).

**Table 1**

Comparisons of descriptive characteristics according to the techniques.

		Technique		<i>P</i> value
		Biplanar (n = 10)	Inverted (n = 10)	
Gender	Male	6 (60,0)	7 (70,0)	<sup>a</sup> 1,000
	Female	4 (40,0)	3 (30,0)	
Age	Mean ±Sd	6,90±1,66	6,50±1,84	<sup>b</sup> 0,538
	Median	6,5 (5–10)	6 (4–9)	
	(Min-Max)			
Surgery time (min)	Mean ±Sd	40,80±5,94	29,00±6,83	<sup>b</sup> 0,001**
	Median	41 (31–51)	31 (19–37)	
	(Min-Max)			
Fluoroscopy exposure time (sec)	Mean ±Sd	27,70±9,25	47,50±6,74	<sup>b</sup> 0,001**
	Median	26,5 (16–43)	46 (39–62)	
	(Min-Max)			
Surgeon Wrist (mR/min)	Mean ±Sd	1,573±0,03	1,605±0,02	<sup>b</sup> 0,820
	Median	2,05	1,95	
	(Min-Max)	(1,05–2,18)	(1,10–2,01)	
Surgeon Neck (mR/min)	Mean ±Sd	0,38±0,04	0,62±0,07	<sup>b</sup> 0,001**
	Median	0,4 (0,3–0,4)	0,7 (0,4–0,8)	
	(Min-Max)			
Surgeon Waist (mR/min)	Mean ±Sd	0,53±0,05	0,57±0,07	<sup>b</sup> 0,185
	Median	0,5 (0,5–0,7)	0,6 (0,5–0,6)	
	(Min-Max)			

\*\* $p < 0,01$ .

<sup>a</sup> Fisher Exact Test Min: Minute Sec: Second mR/min: milliroentgen/minute.

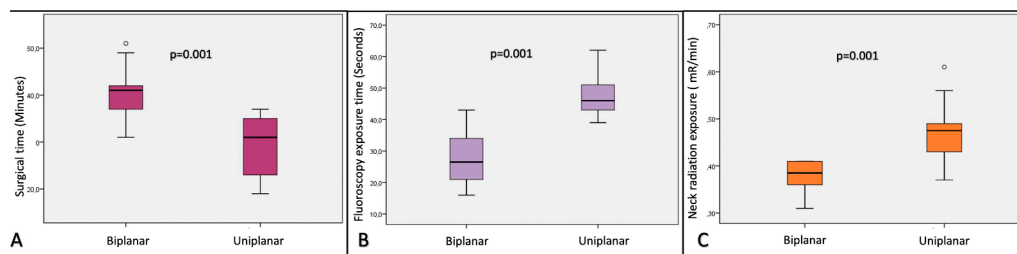
<sup>b</sup> Mann Whitney-U Test.

The measurements on the dosimeters worn by surgeons on the neck were found to be statistically significantly higher while using the uniplanar C-arm configuration ( $0,62 \pm 0,07$  Mr/min) ( $p = 0.001$ ) (Fig. 4). There was no statistically significant difference between the dosimeter measurements on the wrists and waists of the surgeons and the C-arm configurations ( $p = 0.820$ ;  $p = 0.185$ ) (Table 1).

## Discussion

In this study, the effect was investigated of uniplanar and biplanar C-arm use on radiation exposure to surgeons during closed reduction and percutaneous fixation of pediatric Gartland type 3 SHFs. To the best of our knowledge, the current study is the first randomized prospective report on this subject. From the study results, it was determined that the scatter radiation dose received by the surgeon to the neck region in the uniplanar C-arm configuration was higher and the fluoroscopy exposure time was longer. The operation time was longer in the biplanar configuration. No correlation was found between the radiation exposure in the wrist and waist region and the C-arm position.

A few studies in the literature have compared standard and inverted vertical uniplanar positions of the C-arm in terms of radiation exposure [18–21]. However, there is only one retrospective study which has evaluated the effect on radiation exposure of uniplanar (inverted) use with biplanar (horizontal and standard position) use of C-arm in pediatric supracondylar fracture fixation [22]. Schmucker et al. reported no difference between the use of uniplanar and biplanar C-arms, and the duration of fluoroscopy and direct radiation exposure. Scattered radiation exposure was not measured in the Schmucker study because a dosimeter was not used but direct radiation exposure was measured using the equivalent radiation dose emitted by the C-arm [22]. In the current prospective study, a dosimeter was attached to the surgeon's dominant wrist to measure an approximate amount of direct radiation, and to the surgeon's waist and neck region to measure scatter radiation exposure. Schmucker et al. reported that in complex fracture types and when the number of pins used increased, the fluoroscopy time was prolonged and the fluoroscopy time was affected by the surgeon performing the operation [22]. Therefore, in the current study, all factors related to surgery and patients were standardized in order to clearly understand the effect of C-arm position on radiation exposure. To eliminate the factor of surgeon experience, the same surgeon operated in both configurations. Gartland type 3 fractures with a typical pattern were included in the study and the same type of pin configuration was applied to all patients for fixation. Thus, all factors that could affect the



**Fig. 4.** Effect of the C-arm position on (a) surgical time, (b) fluoroscopy exposure time and (c) radiation exposure to the neck region.

radiation exposure and operative time related to simple or complex fracture pattern and pin number were standardized.

It has been shown that there is greater radiation exposure on the x-ray tube of the C-arm due to the back scatter [6,23]. Therefore, the detection of more radiation exposure to the neck region when using the C-arm in the inverted position in the current study is due to the fact that the x-ray tube is closer to the surgeon's neck. Hsu et al. found more scatter radiation exposure to the neck area when the C-arm was in the inverted position, and to the waist area when the C-arm was in the standard position, that is, the image intensifier is uppermost [20]. To the best of our knowledge, the current study is the first to have evaluated scatter radiation exposure in the biplanar position. As the emitter is further from the neck region in this configuration, the amount of scatter radiation to the neck is reduced. In biplanar use, although the emitter is close to the surgeon's waist region in vertical acquisitions, the emitter moves away from the waist region in horizontal acquisitions.

In the current study, the fluoroscopy exposure time in the use of biplanar C-arm was found to be shorter than in the inverted position. This can be attributed to the difficulty in obtaining a suitable lateral view, since the arm has to be rotated for lateral imaging in the use of an inverted C-arm. Stabilization of the arm in biplanar use helps to maintain the reduction, and turning the fluoroscopy 90° to obtain a lateral view makes it easier to obtain appropriate imaging with less use of the C-arm. Gunaydin et al. found that keeping the elbow in a fixed position during pediatric SHF surgery is advantageous in terms of protection of the initial reduction and radiation exposure time [24]. Eismann et al. reported that the fluoroscopy exposure time in the inverted position was significantly longer than in the standard vertical position in pediatric supracondylar humeral fracture surgery. However, the reason for this situation was not clearly explained and the patients were not homogeneously distributed among the groups [21].

According to the current study, the only disadvantage of the use of biplanar C-arm compared to uniplanar use was seen to be the prolongation of the surgical time. This can be considered to be due to the time taken in the transition of the C-arm from the vertical position to the horizontal position when using the biplanar C-arm to acquire a lateral view. Gunaydin et al. found that the use of double fluoroscopy during fixation of pediatric SHFs shortened the surgical time [24]. Gülenç et al. found that the use of double fluoroscopy during fixation of femoral neck fracture shortened the surgical time compared to the use of single fluoroscopy and Abousayed et al. also reported that the use of dual C-arms during calcaneal fracture fixation reduced surgical time [25,26]. The common feature of these studies is that the use of a single fluoroscopy C-arm during surgery prolongs the surgical time due to the need for continuous repositioning. In the current study, the main reason for the prolongation of the surgical time in biplanar use was the change in the positioning of the fluoroscopy C-arm, which supports the above-mentioned studies.

Many studies have shown that surgeons' hands are the body part most exposed to direct radiation during surgery [6,27]. Eismann et al. found that in 10% to 16% of the images taken during closed reduction and percutaneous fixation of pediatric SHFs, the surgeon's hand entered the image and was therefore exposed to direct radiation [21]. Therefore, to evaluate direct radiation exposure in the current study, a dosimeter

was attached to the surgeons' dominant wrists under sterile clothing. The measurements showed that although fluoroscopy time was longer in the uniplanar position, no statistically significant difference was determined between the two techniques in respect of radiation exposure to wrist. It was thought that this could have been due to the continuous movement of the wrist during the surgery. In a cadaver study by Hsu et al., in which supracondylar fracture fixation was mimicked, direct radiation exposure was found to be 21% higher when the fluoroscopy C-arm was in the inverted position compared to the standard position [20].

This study had some limitations. First, surgeons used each method only twice. To be able to evaluate the effectiveness of the methods more clearly, more patients could be operated on and comparisons could be made. Second, we didn't investigate the air Kerma for direct radiation exposure. For this reason, exact measurement of the amount of direct radiation exposure to the wrist could not be made. Third, the radiation exposure of the patients was not measured. However, the lifetime exposure of patients to C-arm radiation is incomparably less than that of surgeons, and it has been shown in a previous study that lead shielding protects the radiosensitive organs of pediatric patients in the surgical treatment of supracondylar humeral fractures [28]. In the current study, it was aimed to protect the patients against radiation by covering their whole body with lead shielding.

## Conclusions

In terms of the parameters evaluated in this study, no difference was detected of a great enough dimension to be able to definitively recommend one method over the other but the most important advantages of biplanar C-arm are that the neck area is exposed to less radiation and it shortens the fluoroscopy time so the use of a biplanar C-arm can be recommended.

## Ethical review committee statement

This study was approved by the institutional ethics committee (Marmara University Medical School, Ethic Committee for Clinical Research).

## Financial disclosure

None declared by the authors.

## CRediT authorship contribution statement

**Servet İğrek:** Methodology, Writing – review & editing, Conceptualization. **Yavuz Şahbat:** Conceptualization, Formal analysis, Data curation, Visualization, Supervision, Writing – review & editing. **Ahmet Hamdi Akgülle:** Formal analysis, Writing – review & editing, Validation. **Bülent Erol:** Writing – review & editing.

## Declaration of Competing Interest

The authors declare no conflicts of interest with respect to the

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