


SCIENTIFIC ARTICLE

Prognostic Factors for the Outcome of Supracondylar Humeral Fractures in Children

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Objective: To detect the influence of the type of osteosynthesis, the timing of surgery, and the experience of the surgeon on the outcome of supracondylar humeral fractures in children.

Methods: In this study we included 97 patients aged 0 to 18 years with displaced supracondylar humeral fractures that required osteosynthesis within a time period of 5 years. In detail, unstable type II as well as type III and type IV fractures were registered. Fractures were treated with Kirschner wire fixation or with elastic stable intramedullary nailing (ESIN). A C-arm was used to control the position of the fragments. Immobilization, if indicated after the operation, was achieved through the fitting of long-arm plaster, or fiberglass splints. The study was carried out retrospectively. The time period to surgery, the duration of the surgery, the type of osteosynthesis, and the experience of the surgeon were determined and correlated to the incidence of complication intraoperatively, postoperatively, and during the long-term follow-up. The hospital's electronic archive, including all charts and radiological studies, was analyzed. Statistical significance was set at an alpha level of 0.05.

Results: Of the 97 supracondylar fractures in this study, 55 (56.7%) occurred in boys and 42 (43.3%) in girls; the average age was 5.8 years. The outcome of the operation was independent of the time interval between the trauma and the operation as well as the mode of transportation ($P > 0.05$) because the complication rate did not differ significantly between patients who had surgery on the same day and between patients who waited for up to 2 days for surgery. Furthermore, the duration of surgery and the experience of the performing surgeon did not influence the occurrence of any complications. However, the complication rate increased after operations performed during the night shift. During the shift between 10 pm and 2 am, the incidence of paresthesia was significantly increased ($P = 0.01$) compared to the shift from 7:30 am to 4:30 pm. However, no difference was detected between business and non-business days regarding any complications. In addition, ESIN and closed reductions resulted in lower complication rates than Kirschner wire fixation and open reductions in this study population.

Conclusion: In our study population, patients undergoing surgery during the night shift, Kirschner wire fixation and open reduction were associated with an increased rate of complications in comparison to operations during the day, closed reduction, and ESIN. Notably, the timing of surgery and the experience of the surgeon did not have any impact on the outcome after supracondylar humeral fracture.

Key words: Complication; Children; Elastic stable intramedullary nail; Kirschner wire fixation; Supracondylar humeral fractures

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Introduction

Supracondylar humeral fractures are the most common elbow fractures in children^{1,2}. Boys are affected more often than girls and the average age in which these fractures occur is 6 years³⁻⁷. The majority of supracondylar humeral fractures are extension-type injuries due to a fall onto the outstretched hand while the elbow is extended². Complications after supracondylar humeral fractures include neurovascular lesions, decreased range of motion, malalignment, and nonunion⁸⁻¹⁴. Although this is a common fracture, controversy exists regarding treatment modalities. Percutaneous pinning is commonly used for displaced fractures. However, antegrade nailing with elastic stable intramedullary nails (ESIN) is a minimally invasive option, if a closed reduction is possible^{7,10,15-20}. While crossed pin placement is associated with the risk of ulnar nerve lesion⁸, there are reports that favor the application of ESIN due to its advantage of minimally invasively implanting the nail *via* a surgical access point that is located on the proximal humerus and far from the fracture site and the ulnar nerve¹⁰. However, to date, only a limited number of papers are available that report on the clinical application of ESIN in supracondylar humeral fractures^{17,18}.

The next factor to be considered is the mode of reduction. Usually, closed reduction remains the first approach for this type of fracture. Nevertheless, if open reduction is needed, controversy exists regarding whether it causes a decrease in range of motion and an increase in other complications¹⁵. Furthermore, the timing of the surgery and the effect of delaying operative treatment have been under investigation previously and have not led to any definite recommendations to date^{4,21-23}. In addition, the experience of the surgeon as well as the duration of the surgery may affect the outcome of the operation.

Therefore, it was the goal of our study to investigate whether these factors significantly change the outcome of the operation. We aimed to: (i) investigate whether the complication rate after osteosynthesis of supracondylar fractures is influenced by the mode of transportation (helicopter, ambulance, private car, or public transportation) as well as by the time period from trauma to surgery; (ii) focus on the question of whether the results of the surgery are the same or possibly even better if patients are operated on the following day as opposed to the day of the trauma; (iii) find out if the operation can be performed safely by young residents when an attending surgeon is present; and (iv) analyze the impact of the type of osteosynthesis on the results of the fracture treatment to guide the planning of the operation.

Patients and Methods

Inclusion and Exclusion Criteria

Inclusion criteria: (i) patients with open epiphyseal plates who needed surgery for supracondylar fractures of the

humerus; (ii) patients with unstable type II fractures as well as all type III and type IV fractures; and (iii) the complication rates after osteosynthesis were compared depending on potential prognostic factors.

Exclusion criteria: (i) patients with open fractures and with vascular injuries due to the fracture; and (ii) patients who underwent any surgical procedures in a different hospital.

Patients

The study was carried out retrospectively. Patients aged 0–18 years with supracondylar fractures that required osteosynthesis with epiphyseal plates who had surgery at our institution during a time period of 5 years were selected from the hospital's electronic radiologic archive. Fractures were classified according to the AO Pediatric Comprehensive Classification²⁴. Analysis was performed using the hospital's electronic archive including all charts, radiological studies, and laboratory studies.

Methods of Treatment

Fractures were treated with Kirschner wire fixation or with ESIN (as previously described by Lacher *et al.*¹⁷). While Kirschner wires are applied at the site of the fracture and have the risk of injuring the ulnar nerve, ESIN are inserted from the proximal humerus. In 1 case, Kirschner wire and screw fixation were combined separately based on the individual decision of the attending surgeon. A C-arm was used to control the position of the fragments. Immobilization, if indicated after the operation, was achieved by the fitting of long-arm plaster, or fiberglass splints.

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. All information was completely anonymized.

Assessment of Outcomes

The following data of the patients were assessed: age, sex, time of trauma, type of fracture, concomitant injuries, vascular and sensomotory status, time of admission to the hospital, mode of transportation and treatment before admission, details of the operation and the hardware removal, medications, complications, and findings from radiological measures and from examinations.

Complications were grouped into three categories: intraoperative complications, complications occurring post-operatively before discharge, and complications that lasted until the last follow-up examination. Complications were recorded in the patient records during the hospital stay and at the follow-up examinations and reviewed within the course of this study. They included impaired range of motion, malalignment, skin perforation, paresthesia, and wound infection. The perfusion and the sensomotory status have been analyzed separately.

The time period to surgery, the duration of the surgery, the type of osteosynthesis, and experience of the surgeon were determined and correlated to the incidence of complication intraoperatively, postoperatively, and during the long-term follow up. Furthermore, it was assessed whether a change in the treatment method (Kirschner wire vs ESIN, closed reduction vs open reduction) was necessary.

Statistics

Pearson's χ^2 test was applied. Statistical analysis was performed using IBM SPSS Statistics 20.0, USA. In cases of $n < 5$ the Fisher exact test was applied. For comparison of more than two groups, ANOVA was applied. Statistical significance was set at an alpha level of 0.05. All data were irreversibly anonymized.

Results

Study Population

The study included 97 patients with supracondylar humeral fractures. Of these, 55 (56.7%) occurred in boys and 42 (43.3%) in girls; the average age was 5.8 years. A majority of supracondylar fractures (54.8%) resulted from playing or sports and 36.1% from falls.

Timing of Surgery

Time Period to Trauma

First, the time interval from trauma to surgery was analyzed and a correlation with the mode of transportation was found. Hence, patients who walked into the emergency room (73.2%) waited longer for surgery than patients who were transported by ambulance or helicopter (26.8%). Most patients had surgery on the same day (56.7%) or on the next day (29.9%, Fig. 1A). Remarkably, the outcome regarding the complication rate and long-term impairment of motion was independent of the time interval between trauma and surgery as well as the mode of transportation ($P > 0.05$). This means that patients who were treated on the same day of the trauma did not show better results than patients who were operated on the following days. Furthermore, no tendency towards better results was seen regarding transportation with a helicopter, ambulance or a private car, or even public transportation.

Time of Day of Operation

Investigations into whether the time of day that the operations were performed affects the outcome revealed that most operations were completed during the day or in the evening and none between 2 am and 7:30 am (Table 1). Notably, during the shift between 10 pm and 2 am the incidence of paresthesia was significantly increased ($P = 0.01$), with a rate of 33.3% (3 out of 9 cases), whereas 6 cases of sensorimotor functional deficits were counted in 52 patients (11.5%) during shift 1 from 7:30 am to 4:30 pm. However, no significant difference was seen regarding any other complications. Furthermore, 71.1% of the operations were conducted on

working days and not on nonbusiness days. No difference in any complications was detected between business and non-business days ($P > 0.005$). Complications were assessed during the hospital stay and at follow-up examinations and included intraoperative and perioperative as well as long-term complications.

Duration of Surgery

The mean duration of surgery was 81 min, whereas the mode of duration values was captured as 50 min. Furthermore, the fastest operation took 20 min and the longest operation took 330 min. There were 6 cases that took longer than 180 min; all of these needed conversion from closed to open reduction (Table 1). Complications arising postoperatively on the ward and after discharge were not registered more often after long operations than after procedures that took less than 90 min.

Impact of Type of Osteosynthesis on the Outcome

The type of osteosynthesis was found to be influenced by the type of reduction where ESIN mainly was applied after closed reduction and Kirschner wires mostly after open reduction. In this study, we included 28 type II fractures; 24 of these were fixated with ESIN while the rest were treated with Kirschner wire osteosynthesis. Furthermore, we present 26 cases of ESIN for the more complicated type III and IV fractures. These were compared to 43 type III and IV fractures treated with Kirschner wire fixation and complication rates were lower after ESIN. It was found that 78.5% of type IV fractures were treated with Kirschner wires (51.3% after open reduction and 27.2% after closed reduction). However, ESIN after closed reduction was possible in 20.5% of type IV fractures and ESIN after open reduction was applied in 1 case (Fig. 2). Remarkably, complications during the hospital stay (Table 2) were more frequent after Kirschner wire fixation ($P = 0.027$). In the follow-up examination, the most frequent complication was the occurrence of an impaired range of motion in 46% after ESIN and 38% after Kirschner wire fixation. Nevertheless, after Kirschner wire fixation additional complications (misalignment [4%], skin perforation of the Kirschner wires [8.9%], wound infection [6%] and 3 patients with paraesthesia) were diagnosed during follow-up visits (Fig. 3A).

Impact of the Type of Reduction on the Outcome

Furthermore, complication rates after open and closed reduction were compared analyzing 66 closed and 31 open reductions. It was revealed that of the more complex type III and IV fractures ($n = 69$), 39 cases could be reduced in a closed manner and, notably, of those, 25 fractures were treated with ESIN and 14 with Kirschner wire fixation. Interestingly, no correlation was found between the method of open reduction and the incidence of postoperative complications during the hospital stay ($P = 0.3$). However, in the follow-up examination, the rate of misalignment and delayed consolidation according to the X-ray, as well as skin perforation by Kirschner wires and wound infections, was increased

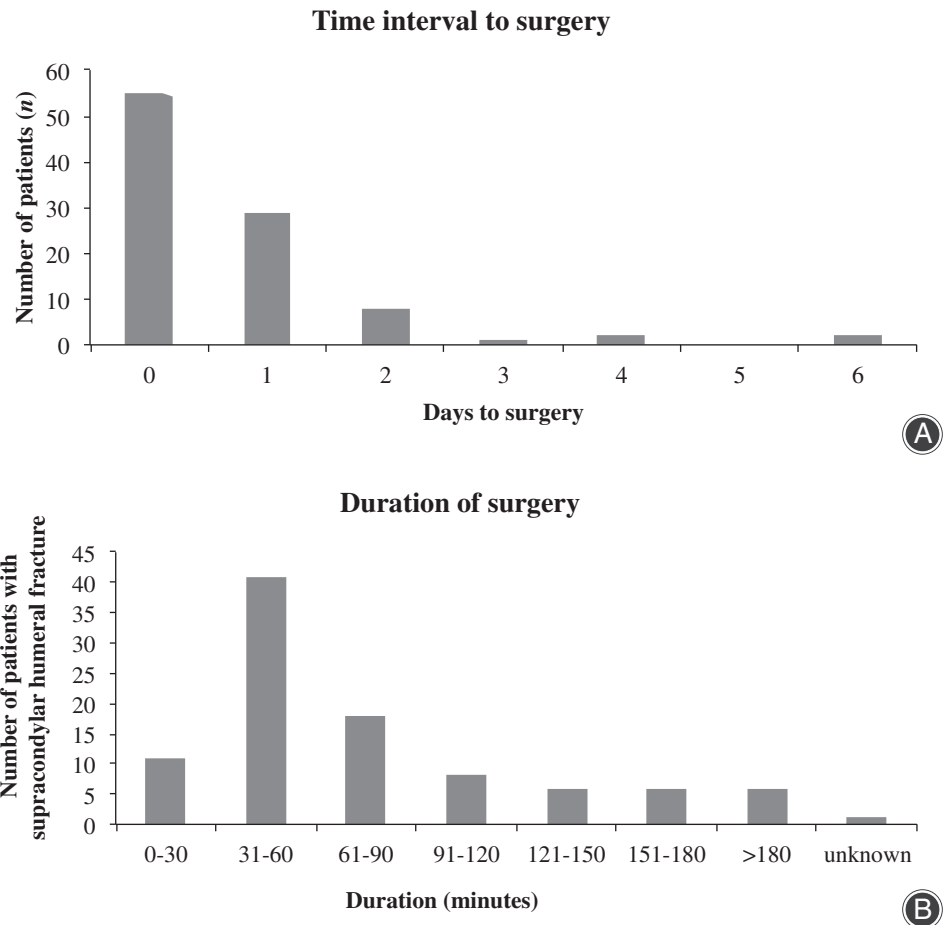


Fig. 1 Analysis of the timing of the procedure. (A) The time from trauma to surgery and reveals that the majority of patients was operated on on the day of the trauma or 1 day after.

(B) Demonstrates that most procedures took 1 hour.

after open reduction, with 29% in comparison to 9% after closed reduction ($P = 0.002$) (Fig. 3B). Nevertheless, the incidence of paresthesia was assessed by clinical examination and nerve conduction velocity testing during the follow-up visits and was higher after closed reduction. In detail, after open reduction, no patient showed any sensomotory deficit during the follow-up visit, whereas 3 patients who had undergone closed reduction revealed a sensory deficit.

Experience of the Surgeon

In order to compose training programs for surgeons, the qualification of the surgeon who performed the osteosynthesis was assessed. For every procedure, a

consultant or attending physician was present. However, most operations were undertaken by experienced residents (40.2%) or consultants themselves (36.1%, Table 3). Here, the rate of complications that were detected after supracondylar humeral fracture was independent of the experience of the surgeon ($P > 0.05$).

Discussion

This study analyses parameters potentially influencing the outcome after osteosynthesis of supracondylar humerus fractures in children. Our data clearly suggest that Kirschner wire osteosynthesis, in comparison to ESIN, and open reduction as well as timing of surgery during the night shift between 10pm and 2am result in an increase of postoperative complications. However, the time interval to surgery following the fracture, as well as trauma mechanism, mode of transportation, duration of surgery, and experience of the operating surgeon in the presence of a consultant pediatric surgeon do not influence the occurrence of complications.

The major choice at the beginning of surgery is the mode of osteosynthesis. The comparison of Kirschner wire fixation to ESIN revealed a significantly lower complication rate after ESIN. While, according to the literature, SCHF type III and IV are mainly fixated with Kirschner wires,²⁵

TABLE 1 Time of day that surgery was performed

Shift	Time	Number of operations	Percentage of all operations
Shift 1	7:30am–4:40pm	52	53.6
Shift 2	4:31pm–10:00pm	36	37.1
Shift 3	10:01pm–2:00am	9	9.3
Shift 4	2:01am–7:29pm	0	0
All	—	97	100

Type of osteosynthesis for supracondylar humeral fractures

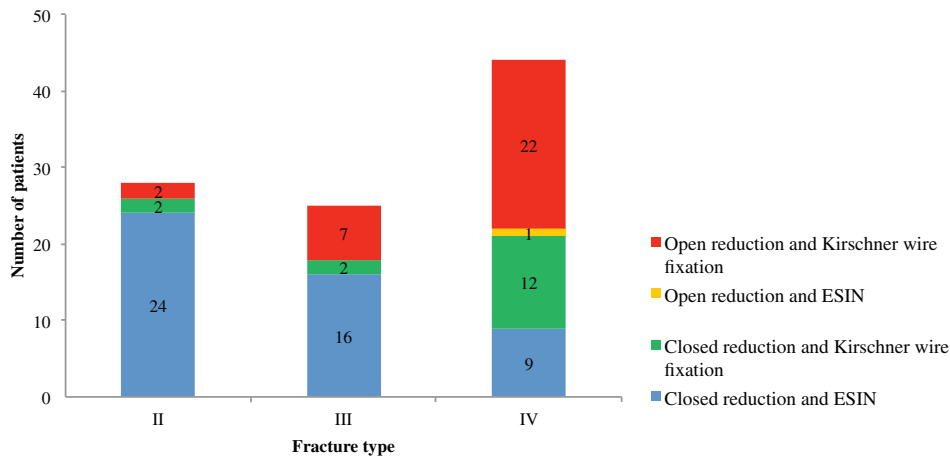


Fig. 2 Analysis of the type of osteosynthesis was conducted and showed that for type II and III fractures mainly elastic stable intramedullary nails (ESIN) were applied whereas type IV fractures were treated mainly with Kirschner wires. However, almost half of the type IV fractures were reduced in a closed manner.

TABLE 2 Postoperative complications after ESIN and Kirschner wire fixation

Type of osteosynthesis	n	Number of complications	Impaired range of motion	Misalignment	Skin perforation of pin/nail	Paresthesia	Wound infection
Closed reduction and ESIN	49	22	22	–	–	–	1
Closed reduction and Kirschner wire	16	7	5	–	–	3	1
Open reduction and ESIN	1	–	1	–	–	–	–
Open reduction and Kirschner wire	29	4	12	2	4	–	2
Other	2	–	2	–	–	–	–

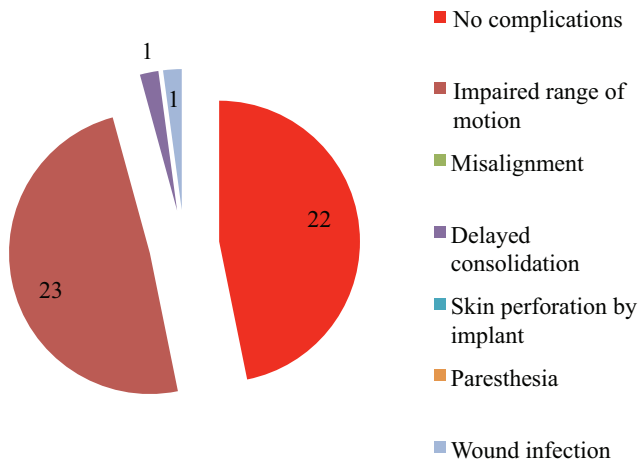
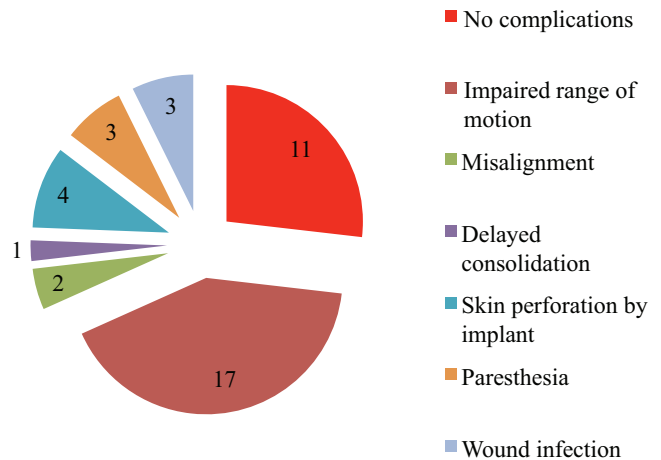
–, none; ESIN, elastic stable intramedullary nailing.

the treatment of unstable type II supracondylar fractures has been a subject of controversy²⁰ because simple immobilization or cuff and collar are as well accepted²⁶ as closed reduction and Kirschner wire fixation. However, the method of closed reduction and ESIN has been reported to have good results in type II fractures as well^{17,18}. In this study, we included 28 SCHF type II fractures; 24 of these were fixated with ESIN, while the rest were treated with Kirschner wire osteosynthesis.

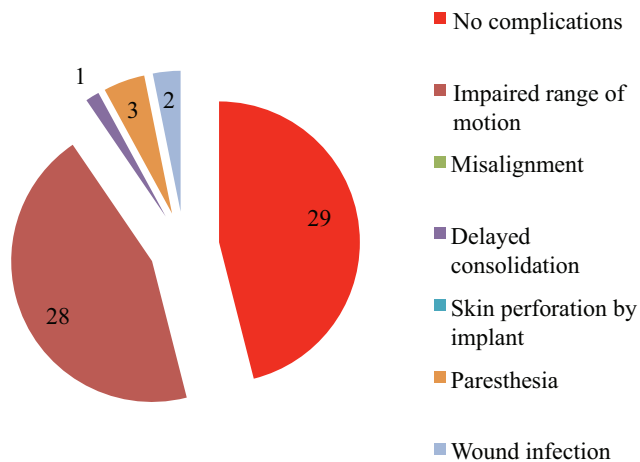
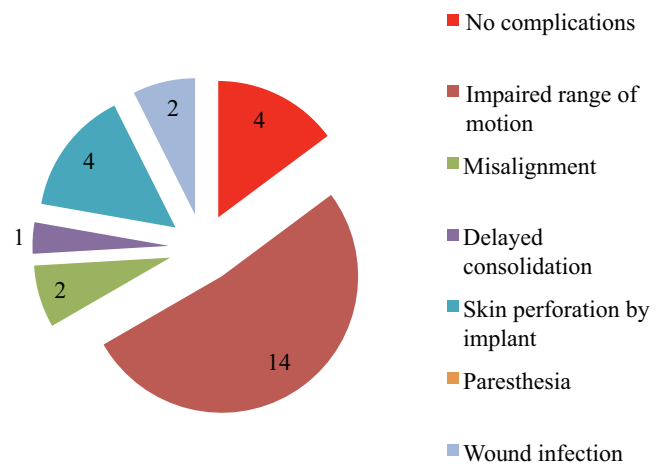
Elastic stable intramedullary nailing is usually not applied for more complex fractures, including type III and IV fractures, and Kirschner wire fixation is still regarded as the standard procedure²⁵. However, we present 26 cases of ESIN for these more complicated fractures. These were compared to 43 type III and IV fractures treated with Kirschner wire fixation and better results were revealed than for Kirschner wire fixation. However, in our study we found that not only does open reduction increase the risk of complications after surgery in comparison to closed reduction, but the mode of osteosynthesis was also shown to change the rate of complications because we found a higher incidence of complications after Kirschner wire fixation. An advantage of ESIN is that the cast-free treatment after surgery¹⁷ as

opposed to cast treatment for 4 weeks after Kirschner wire fixation leads to early mobilization and less impairment during everyday activities. Furthermore, the necessity of exact anatomic reduction to place the nails into the distal humerus allows for no more than 10° of rotational malalignment as well as avoiding the development of cubitus varus and valgus¹⁷. Another advantage is the protection of the ulnar nerve by introduction of the ESIN at the proximal humerus as opposed to a risk of 3%–4% for ulnar nerve lesions with the use of Kirschner wires⁸. These benefits seem to rule out the drawbacks that are being discussed, including the need of two surgeons for this procedure or possibly prolonged operations. Interestingly, the main postoperative complication that occurred after ESIN in our study is an impaired range of motion. However, there is a similar rate of impaired range of motion after Kirschner wire fixation, so that this finding in combination with the lower rate of infection and pin perforation as well as the abovementioned advantages with good functional results lead to our recommendation of using ESIN for the treatment of supracondylar humerus fractures in children, and especially for type III and IV supracondylar fractures.

Another major factor under discussion is timing of surgery²⁵. Because nerve lesions and vascular lesions must

Complications in follow up after ESIN ($n = 50$)**Complications in follow up after kirschner wire fixation ($n = 45$)**

A

Complications after closed reduction ($n = 66$)**Complications after open reduction ($n = 31$)**

B

Fig. 3 (A) Complications during follow up were considered and a lower rate was noted after elastic stable intramedullary nail (ESIN) than after Kirschner wire fixation. Two cases of a combined osteosynthesis with ESIN/Kirschner wire and screw/Kirschner wire were excluded in this analysis. (B) Comparison of closed to open reduction demonstrated a higher complication rate after open reduction.

inevitably be treated immediately, these cases were excluded from this study. Analysis of the time period between trauma and surgery revealed no increased rate of complications when surgery was postponed. Although this study only differentiated the day of trauma and the number of days after trauma as opposed to recording the hours after trauma as

done in other studies^{22,27,28}, our data provide evidence that surgery on the day of trauma does not enhance the outcome of surgery. However, although there are reports that are in agreement with this finding^{22,27,29}, our results are in contrast with several other studies that have reported more complications^{21,30,31} after operations that have been postponed.

TABLE 3 Number and percentage of the performing surgeon according to their level of experience

Level of experience	Percentage of operations performed
Young resident	11.3
Experienced resident	40.2
Consultant	12.4
Attending	36.1

Nevertheless, after analyzing a large study population here and in agreement with the latest studies addressing this question, we conclude that the operation should be postponed to avoid the night shift. Furthermore, although previous studies by Goldstein³² and Bell and Redelmaier³³ have discussed the “weekend effect,” with an increased rate of complications after surgery on the weekend, this study cannot confirm their findings because complications were not detected more often when operations were performed on the weekend.

In the literature, controversy also exists regarding the experience of the surgeon. Some previous reports have stated that experience improves the outcome^{30,34} because 75% of problems after surgery are related to the surgeon³⁵, while others deny that the experience influences the occurrence of long-term complications^{36,37}. In this study, we could not detect any difference between the outcome of fractures that were operated on by an experienced surgeon or a resident. However, if a resident was performing the surgery, there was always a consultant assisting. This is in agreement with the

recommendation of a previous study³⁸ and is especially relevant for the training program of surgeons because this study emphasizes that letting a young surgeon perform the osteosynthesis of any supracondylar humeral fracture in the presence of a consultant will not increase the risk of complications and can, therefore, be included in the training program. Because skills must be acquired by the residents during their training, this is a very important finding³⁹.

The limiting factors of this study are its retrospective design that also made it impossible to introduce classifications of symptoms that we assessed (e.g. the degree of pain). Furthermore, the observation period was quite short and we need to perform a follow-up study to evaluate the long-term outcomes of the operations.

In conclusion, we found that the outcome after supracondylar humeral fracture in children was better after closed reduction and ESIN than after Kirschner wire fixation and open reduction in our study population. Notably, the complication rate was significantly lower after operations that were carried out during the day shift and not in the late night shift. In this study, the trauma mechanism, the mode of transportation, the time interval to surgery, as well as the duration of the procedure did not influence the outcome, and the operation could be performed safely by a resident.

Disclosure

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