RESEARCH ARTICLE

"DOUBLE X" FIXATION FOR RARE AND PARTICULAR PEDIATRIC SUPRACONDYLAR HUMERUS FRACTURES

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List of Abbreviation:
SHF = supracondylar humeral fractures; CRPP = closed reduction and percutaneous pinning; ORIF = open reduction and internal fixation; epitrochlear approach = EA; mMA = minimal medial-approach; mORIF = minimal-open reduction and internal fixation; AHL = anterior humeral line; LCHA = lateral condylo-humeral angle; HCA = humero-capitellar angle; mORPP = minimal-open reduction and percutaneous pining; CA = carrying angle; BA = Baumann angle; ESIN = elastic stable intramedullary nailing, PSHF = particular supracondylar humeral fractures.

Abstract

Background Context. The presence of special, rare and various forms which we can encounter when treating supracondylar humeral fractures (SHF) in children, call into question what therapeutic methods can be used to increase the effectiveness of the treatment applied. The aim of this paper is to present the results obtained by using double cross-fixation, "in double X", by closed reduction and percutaneous pinning (CRPP) or open reduction and internal fixation (ORIF) in treating rare and particular forms. Comments and opinions on "double X" method and other cross or side configurations are presented.

Patient Sample. All patients with rare and particular forms presented in this article, were operated during 2001-2020 in state and private hospitals. Fixation in "double X" was used either by CRPP and ORIF. The epitrochlear approach (EA) was performed in cases where stability by CRPP could not be ensured or when there were clear signs of ulnar nerve damage. The minimal medial-approach (mMA) highlights the epitrochlea and the fracture of the medial pylon; it has the role of anatomically reducing the medial pylon, thinner and very unstable in rare and particular forms. During 1982-2020 we consulted, treated and evaluated patients with SHF to whom all known treatment methods were applied: orthopedic reduction and immobilization in plaster cast, CRPP, ORIF, minimal-open reduction and internal fixation (mORIF) by mMA and external fixator. Internal fixation was done by the techniques of Judet, San Antonio, San Diego, Dorgan or Burnei, in "X" and "double X". In 2001, I introduced "double X" fixation to better stabilize anatomical reductions that showed signs of instability during intraoperative verification.

All indications given in the study protocol have been made in accordance with the regulations mentioned in the experimental program.

Results. All SHFs operated by CRPP and ORIF by "double X" were cured and satisfactory and good results were obtained in the neglected types operated between 14 and 60 days and good and excellent results were obtained in the rare forms.

Conclusions. "Double X" fixation gives the best stabilization and postoperatively there is no need for immobilization in a plaster cast. Recovery may begin the day after surgery.

Keywords: supracondylar fractures, child elbow pathology, cross-fixation, lateral fixation, healing and recovery after 30-45 days.

1. Introduction

There are two types of supracondylar humeral fractures (SHFs), by extension and by flexion. Fractures by extension are recorded in the literature as having a frequency between 95-98% and those by flexion 2-5% [1]. In our statistics SHFs with displacement were by extension in 99% of cases and by flexion 1%. Rare forms of SHFs have a number of peculiarities, both in establishing the diagnosis and in choosing the therapeutic method. Often, in order to correctly establish the diagnosis of these forms, in addition to radiological examination, other imaging examinations are required. For obtaining healing and functional recovery, various approaches and several ways of fixation can be used, either crossed or lateral: in X, Dorgan or Burnei, Judet, San Antonio or San Diego (Fig. 1).

Fig. 1

Different configurations for osteosynthesis with K-wires. **A.** Cross configuration; **B.** Double-cross configuration, Burnei technique; **C.** Lateral cross configuration, Dorgan technique; **D.** Side configuration; **E.** Configuration with three lateral K-wires, San Antonio technique; **F.** Configuration with two lateral K-wires and one medial, San Diego technique. (Diagrams according to: Gómez VE, Gil Albarova J, Herrera A. Revisión y actualización del tratamiento de las fracturas supracondíleas de húmero en la infancia. Rev Esp Cir Osteoar. 2013;48(255):110-22.

In such difficult cases it is important to choose the most effective method, given the vulnerability of stabilization and the occurrence of severe complications. The remodeling of residual deficits is limited, and the correction of the gap, varus, valgus or stiffness requires other operative interventions. Data on sagittal plan remodeling are recorded in the literature.

Malunion occurs after both orthopedic and surgical treatment in more than half of the patients. The distal fragment is most frequently consolidated in extension. The center of the capitellum is positioned posteriorly relative to the anterior humeral line (AHL). The average hyperextension movement of the capitellum behind the AHL occurs in approximately 65% of all patients. Although K-wire pinning was considered unsatisfactory in 1/3 of cases, significant malunion was rare [2].

After treatment, sagittal remodeling takes

place 100% for 60% of patients, 30% remodeled so that the AHL passes through the central third of the capitellum and 10% remodel minimally or not at all [3]. Sagittal remodeling has limits on the degree of movement and age of the patient. Children under the age of 5 have the maximum remodeling capacity. The limit of remodeling is also offset by the process of growth and development, present and intense in preschool children.

In patients whose orthopedic reduction was followed by percutaneous pinning, 84% of them obtained good and excellent results appreciated according to Flynn's criteria, without an appreciable difference based on open or closed fractures [4]. Although K-wire pinning was considered unsatisfactory in one third of cases, significant malunion was rare [2].

Currently, the limits allowed by age groups and the certain methods for assessing the displacement of the humeral palette after reduction are not known, when the displacement is not unique. Frequently the displacements are associated, tilting-translation-shift-varus or valgus. In type II and III Gartland fractures, at least 2 types of displacements are common, often 3. The gap is almost never missing. Firm fixation of an anatomical reduction is the safe and effective solution for rapid healing and recovery.

2. Patient sample and method

In 2001, I introduced "double X" fixation to better stabilize anatomical reductions that showed signs of instability during intraoperative verification.

The evaluation method took into account the classification of SHFs into rare and particular and the complications of these fractures, operated by fixing "in double X".

The types of rare and particular fractures were: neglected at 14-60 days from onset 19.3%, SHFs in obese 16.1%, pediatric T-condilar fractures 12.8%, transphyseal, associated with ipsilateral forearm fractures, after malunion and comminutive transolecranian, 3% each, and those by flexion and osteogenesis imperfecta, 2% each. Complications included elbow stiffness, accounting for 41% of cases, varus 36.4, valgus 13.6 and hyperextension 9% (Table 1).

Table 1 – SHFs, rare and particular, circumstantially classified and complications treated by “double X” fixation

No.	Types of rare and particular SHFs	No. of cases	Percentage
1.	In flexion	2	6.5
2.	Transphyseal	3	9.7
3.	Supracondylar T fractures	4	12.8
4.	Associated with same side forearm fractures	3	9.7
5.	In obese patients	5	16.1
6.	In osteogenesa imperfecta	2	6.5
7.	Neglected, after 14-60 days from the accident	6	19.3
8.	Iterative after malunion	3	9.7
9.	Unusual (through the olecranon)	3	9.7
Total rare and particular cases		31	100
10.	Elbow stiffness	9	41
11.	Varus	8	36.4
12.	Valgus	3	13.6
13.	Hyperextension	2	9
Total complications		22	100
Total SHFs + complications – 53 cases			

Data from statistics made by A. Breha
and cases treated by Gh. Burnei

The evaluation criteria were assessed by measuring flexion and extension at 14, 25, 30, 35 and 45 days and then at 3 and 6 months for patients with elbow stiffness.

For the radiological evaluation we used the following data: BA, AHL, LCHA, HCA and assessment of the olecranon fossa by shape and size.

2.1 Rare and Particular Forms

From the clinical and radiological evaluation, rare and particular forms attract attention. In some cases, in order to elucidate some details of diagnosis and treatment, complementary explorations are necessary: arthrography, CT, MRI, etc. When SHF occurs on the background of genetic conditions that can be diagnosed at first sight or when SHF are neglected old fractures, the surgeon wonders if the usual methods are usable and then turns to a safe and effective treatment method, adapted to each case.

2.1.1 The Flexion-Type SHF

The supracondylar flexion type fracture in humerus is a rare fracture in children. The lesion is caused by a direct fall on the tip of the elbow that causes hyperflexion of the infracondylar segment. This fracture is unstable, it is difficult to reduce by push-pull with a joystick fixed in the distal fragment [5]. Fixing in "double X" ensures a verifiable intraoperative, solid and safe reduction. At repeated attempts to reduce or resume the reduction of grade III or IV fractures, the posterior fractures can be transformed into anterior fractures by translating the distal fragment. There is probably a substantial overlap between type IV and flexion fractures. Type IV fractures were associated with a longer operating time and were treated with open reduction more frequently than type III fractures [6].

In the studied group we encountered two cases of flexion fractures. In both cases, orthopedic reduction and immobilization in a cast were performed. Secondary displacement was followed by surgery. The oblique trajectory of the fractures induced a marked instability. In both cases, reduction and ”double X” percutaneous pinning were used.

2.1.2 Transphyseal Fracture

These are low supracondylar fractures of the humerus. Their incidence is usually present in children under 3 years of age and occurs as a result of obstetric trauma, Silverman syndrome or as a result of trauma by falling. Prompt and accurate diagnosis of the lesion is essential for proper treatment. Recognizing that the forearm is not aligned with the humerus on plain radiographs may help diagnose the lesion [7].

A thoracic limb with a clinically and radiologically interrupted axis, which is also associated with the presence of "soft crackles" of the chondral type, guides the diagnosis and requires surgical treatment. In a vast majority of cases, the trajectory of the fracture line passes a few millimeters above the growth cartilage, in full humeral palette. In a smaller proportion, 9%, the fractures affected the growth cartilage, the most common being the Harris-Salter type I and II fractures. Closed reduction and percutaneous pinning (CRPP) techniques are used in these cases. Varus elbow and humerus shortening appear very frequently due to young age of children and interest of the growth cartilage. Treatment of transphyseal fractures by surgical approach, open reduction and internal fixation (ORIF) and immobilization in plaster splint is effective and reliable; the rate of good and excellent results is about 98% [8].

To avoid growth disorders, these fractures are treated by ORIF to obtain an anatomical reduction. The operating technique must be impeccable. The "double X" fixation ensures fast and complete healing and recovery of elbow mobility. Varus or valgus elbow and humerus shortening occur extremely rare.

We operated on three patients with transphyseal fractures: one by CRPP and two by ORIF. The fragments were reduced anatomically and functional recovery was complete after 30 days.

2.1.3 Pediatric T-condilar humerus fracture

The T-fracture is rare, offers unique challenges and the mechanism of production may be common to those of the adult [9]. In children under 8 years of age, the lesion is extremely rare. In the English language literature, 55 cases of

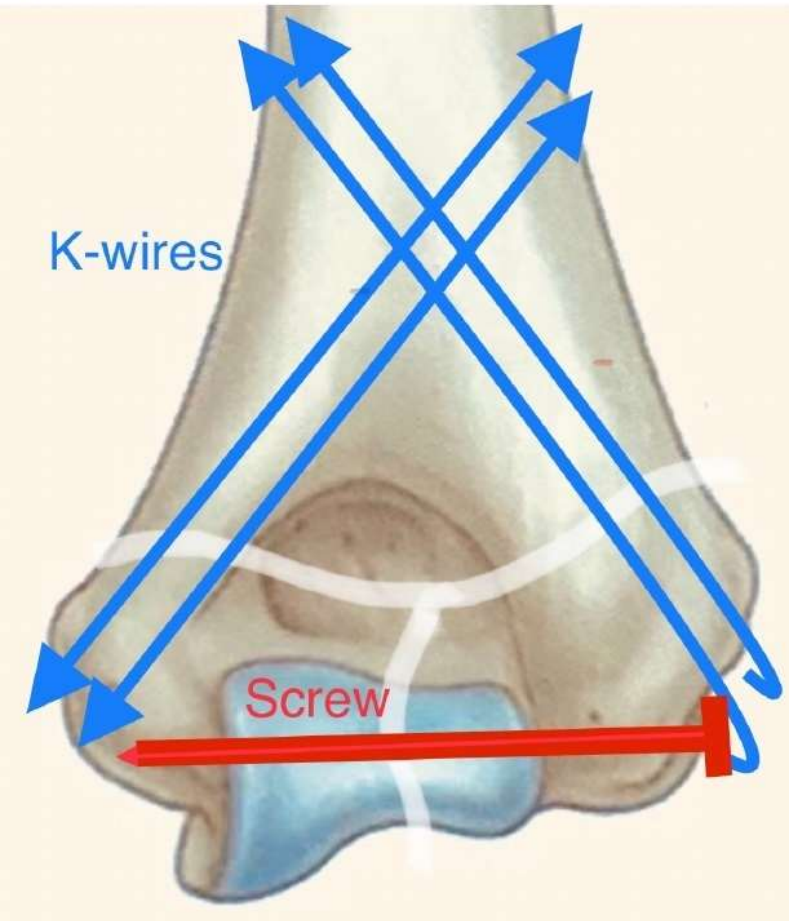
SHF have occurred in children, of which 12 were children under the age of 8. The low frequency of these fractures means that in the literature this topic is approached extremely rare and there is no consensus on treatment [10].

In younger patients, CRPP remains a viable option, but for older adolescents, ORIF ensure stable elbow fixation and the most reliable restoration of the joint surface [9].

Cross-fixation in "double X" provides very good stability in supracondylar T-fractures. Tomori [11] reports a case of intercondylar fracture of the distal humerus in a 7-year-old boy who could not achieve reduction by CRPP, the fragments being unstable and irreductible. After the failure of the closed reduction, it carried out the ORIF by a posterior approach. Double cross-fixation ensured the stability of the intercondylar fracture. After 13 months postoperatively, the child did not have functional disorders or other injuries. The trans-olecranon approach exposes the fragments better, especially when there are multiple comminutions, and a good tension-band fixation does not require cast immobilization. In these fractures, the pain sensitivity of some children can be overcome only by 5-7 days of immobilization.

When a better osteosynthesis is required, in addition to the double cross configuration, the two distal fragments, lateral and medial, are fixed either with a screw or with two threaded pins. In the 4 operated cases we used to compact the two distal fragments, in one patient two threaded pins and in the other three, screw was used. Sponge screws, of appropriate size, passed under the growth cartilage, ensure better containment. The containment of the three fragments is good and gives the surgeon safety after checking it intraoperatively (Fig. 2).

Fig. 2



Supracondylar T fracture. The distal fragments are fixed with a transverse screw and the "double X" configuration strengthens the two fragments with the proximal fragment.

The results are better than those obtained in adults, but often poorer than other elbow fractures in this age group [9].

2.1.4 Association with Ipsilateral Forearm Fractures

This association encountered in injuries caused by high-intensity traumatic agents is also known as floating elbow. SHF associated with fracture of both forearm bones is a rare injury, that occurs after trauma with high energy and require surgery. In the past, there was high frequency of compartment syndrome after these fractures. Gartland type II or III SHF associated with fracture of both forearm bones give a high degree of instability at the elbow.

The forearm fracture can be treated by closed reduction if the SHF is well fixed. Postoperative cast immobilization is safe and is not followed by the onset of compartment syndrome or the resumption of reduction [12]. The cross-fixing in "double X" provides safety to the reduction and avoids its loss by secondary movement under the plaster. To avoid immobilization and a long recovery period, elastic stable intramedullary nailing (ESIN) with titanium elastic nails (TEN) of forearm fractures, eliminates immobilization in plaster splint and allows rapid recovery. Reduction and fixation with K-wires in "double X" of SHF can also be done by percutaneous pinning.

In the analyzed case studies, SHF was associated with two cases of “floating elbow” by fracturing both bones of the forearm in the proximal third and another two cases with fracturing the radius in the middle third. In all cases, a good fixation by ESIN of the ulna and radius fractures was applied, followed by the fixation “in double X” by CRPP, without immobilization in a cast and early mobilization of the respective limb.

2.1.5 Obesity and SHF

Obesity in children has become a real issue in orthopedic pathology and the study of the effects of this condition in SHF requires appropriate measures regarding the choice of treatment methods. SHF in obese children is often more complex. Their frequency is not well known and the databases are misinterpreted. Some authors give the impression that obesity in children with SHF is a much smaller problem than in reality [13].

Obese children find it harder to bear cast immobilization. Closed reduction or CRPP followed by plaster immobilization move secondary and require resumption of reduction or ORIF. ORIF has become a commonly used method in obese children and the frequency increases with age in those with private insurance [14]. Parents of obese children with SHF should be aware of the risk of therapeutic guidance in the direction of surgery and the need for surgery as an effective and comfortable solution in postoperative prognosis.

We encountered 5 cases of SHF in children aged 8 to 12 years who weighed between 50 and 110 kg. All children were operated using ORIF. In only one case we noticed delay in full recovery of elbow mobility.

2.1.6 SHF with Osteogenesis Imperfecta

A secure and solid fixation in high forms of SHF in children with osteogenesis imperfecta can prevent atrophic pseudarthrosis. Plaster immobilization can induce lack of osteogenesis at fracture site and the appearance of pseudarthrosis. Supracondylar fractures and those at the metaphyseal-diaphyseal junction can be fixed in "double X". The use of K-wires gives even greater safety to osteosynthesis. The firmness of osteosynthesis in double X and the lack of immobilization are factors that favor these rare cases and avoid the appearance of a serious complication, pseudarthrosis. Atrophic pseudarthrosis of the distal humerus in children with osteogenesis imperfecta is a cause for concern [15].

Traditional treatments, such as cast, intramedullary rods and bone graft, have not been successful in a 2-year and 10-month-old child with type III osteogenesis imperfecta. An SHF in the presence of other disorders in the distal extremity of the humerus requires reconstruction to restore the functionality of the elbow. In two cases, in order to avoid malunion at the fracture site, an

osteotomy was performed followed by repositioning and fixation; one of these patients also needed an osteotomy at the base of the olecranon and tension-band fixation. The anatomical reconfiguration of the elbow allowed the recovery of flexion and extension.

2.1.7 Neglected fractures treated by open reduction after 14-60 days from onset

For patients with SHF who see a doctor between 14 days and 60 days after the fracture, the presence of callus does not allow CRPP. There are 2 options in these cases. As a first option, recovery treatment can be started and later, after the maximum recovery limit is reached, an osteotomy is performed to correct the axial deviation in the varus or valgus. We have adopted this attitude in two cases. The disadvantage of this attitude is that if there is loss of mobility that is sometimes unrecoverable. The second option consists of ORIF with K-wires. Using this variant we operated 4 cases. During the first 14-60 days the hypertrophic callus can be peeled off. Evaluation of the results in children with SHF operated after 14 days by previous approach, analyzing the Bauman angle, K-wires configuration, carrying angles, Mayo Elbow performance score and Flynn criteria showed that the distant results are poor [16].

Lateral, medial or double approach (both lateral and medial), rigorous and non-aggressive dissection, pinning in "double X" without immobilization with rapid resumption of elbow mobility allows recovery of elbow mobility and reduces recovery period that can reach one year after immobilization in plaster cast [17]. The peeling of the proximal fragment is done "in situ". After peeling, there can be observed the position of the proximal fragment in relation to the position of the humeral palette. The dissection of the distal fragment clearly highlights the vicious position in which the fracture was consolidated. The vicious position of consolidation is maintained by the interfragmental callus, when the dissection is done thoroughly, although the pericortical callus has been removed. Slowly, carefully, the malunion refractures. The olecranon fossa is checked and released from small bone conglomerates and cortical fringes that can generate bone growths that can oppose the extension movement.

Pinning the medial pylon, reconfiguring the olecranon fossa so that there is an anatomical olecranon-olecranon fossa congruence are essential elements that ensure healing and functional recovery. The medial pylon is initially fixed only with a retrograde-to-anterograde K-wire. It allows some mobility in the transverse plane and facilitates the placement of the 2 retrograde K-wires on the lateral pylon in such a way as to anatomically reconstruct the olecranon fossa. For the correct positioning of the fragment, AHL is appreciated intraoperatively, and the placement of the 2 K-wires on the lateral side will take into account this trajectory. The 2nd K-wire on the medial pylon is fixed on the guide and finalizes the solidity of the “double X” mounting. The firm fixation, verified intraoperatively, allows mobilization immediately postoperatively. Sometimes, as a result of initial lesions of the olecranon fossa or secondary to anarchic osteochondral regeneration, reconfiguration of the fossa and positioning of the condyle centered on the AHL, requires a reduction that seems nonatomical.

Bănculescu [18] considers that intraoperative analgesic technique, by using intravenous opioid agents - fentanyl and possibly NMDA uncompetitive antagonist receptors - ketamine, preemptively complements postoperative pain management, preventing the phenomenon of central facilitation, which would inevitably lead to “pain memory” and consequently persistent pain. Adequate pain control in the first 3 days postoperatively, especially in the first 24 hours, contributes significantly to rapid and complete recovery of young patients, having a positive impact on their mental state. Most of them receive standardized IV doses of analgesics: acetaminophen, non-steroidal anti-inflammatory drugs – ketoprofen, metamizole, opioids - morphine, which effectively cut the pain, allowing them to actively mobilize their elbow, supported by the entourage. The persistence of pain on the 5th postoperative

day requires clinical and radiological evaluation.

In neglected forms, treatment is performed in recovery centers and the patient is reviewed weekly by the surgeon. Thus, from the 7th postoperative day, approximately 3 children flex their hand to the nose, and after 30-35 days 5 of 6 cases fully recover flexion and extension.

2.1.8 Iterative fractures after malunion

Iterative SHF is rare. It is a complication that a patient may present after a few weeks. In fact, it is a new elbow fracture preceded by a supracondylar fracture of the humerus. The treatment of this new fracture will depend on the position of the distal fragment [19]. Vicious consolidation in extension or flexion and ligament hyperlaxity increase the rate of recurrent fractures and facilitate the biomechanical mechanism of refracturing by the action of the olecranon. A vicious fracture in extension predisposes the patient to a second fracture [20-22]. The effect of hyperextension and ligament laxity on the incidence of fractures is obvious. A child with ligament laxity has an increased risk of developing a recurrent fracture after a supracondylar fracture consolidated in extension, compared to a forearm fracture [23]. Refracturing can also occur after two years from a transverse fracture healed in moderate extension. Abnormal joint mechanics induced by a post-traumatic deformation in extension associated with a secondary ligament laxity, further decreases the resistance of the supracondylar area, the area with low resistance in its anatomical configuration [21].

Our study includes 3 patients with malunion fractures, two of whom were footballers at a children's sports club. Through ORIF, an anatomical reduction and a solid fixation with "double X" pinning was performed. At 3 months, the two patients resumed their sports activity.

2.1.9 Approaching Unusual SHF

These are cases in which the intensity of the trauma produces the protrusion of the olecranon and the cominution of the bone blade that outlines the olecranon fossa. Fractures can sometimes be more complex and can be accompanied by the cominution of one pillar, more often the radial pillar. We encountered 3 cases difficult to treat, fixing "in double X" was difficult. It was actually the beginning of "double X" osteosynthesis.

In medical practice there are certain cases of SHF, as in fact in other pediatric orthopedic diseases, which differ from the classic, standardized models. In these cases, young specialists and inexperienced residents with preconceived notions who see surgery only in guides and templates, become opponents of older doctors who apply experience, scholarship and innovative medicine. Their desire to simplify everything in order to get to it as quickly as possible, rises the philosophy of principles applied to unusual fractures [23]. The intentional or unintentional confusion between malpraxis, complications and innovative medicine is deplorable, a prerogative of superficiality and incorrect medical achievement.

2.2 "Double X" fixation of osteotomies performed to correct some complications

2.2.1 Elbow stiffness

Loss of mobility occurs more frequently in case of fractures treated by open reduction, due to a greater inflammatory reaction and when surgical maneuvers become more aggressive to a complex fracture with pre-existing lesions. Losing and neglecting the reduction can be the cause of loss of mobility. Thus, after hyperextension consolidations there will be a tendency to limit flexion, and fractures consolidated in hyperflexion have limited extension [25]. There is a higher risk of this complication in those cases where treatment is delayed. Approximately 10% of patients with Gartland type III fractures who presented late and suffered a failed reduction had a loss of mobility of more than 15 degrees [26].

Partial or total loss of elbow mobility are severe complications. The attempt to partially or totally recover a joint mobility is made through a reconstructive operation after a complete imaging evaluation. The destruction of hyaline cartilage and the presence of extensive osteoarthritis considerably limits the chances of recovery by reconstructing the joint. Stiffness that has an operative indication is addressed by

transolecranial osteotomy. The viciously positioned humeral palette is better repositioned after supracondylar osteotomy.

Out of the total number of patients with rare, particular and complicated fractures, a group of 9 children presented elbow stiffness. All needed reconstruction of the elbow by supracondylar humerus osteotomy and olecranon osteotomy, performed at its base, without affecting the large or small sigmoid cavity (growth cartilage). The fixing was done with a cross configuration in "double X", respectively with a tension band for the olecranon to ensure early mobilization.

After fixing in "double X", children undergo recovery treatment through early active and passive mobilization. It is essential that mobilization is slow and progressive to the point of pain. Pain control is done in a therapeutic regime, synchronized with recovery sessions. The results are satisfactory and good.

2.2.2 Varus or valgus elbow and hyperextension elbow

By location, high, extra-articular SHFs have an incidence of 6%. The most common fractures, 85%, are located through the olecranon fossa above the growth cartilage and 9% pass under the cartilage. The appearance of a varus elbow after a long period in children with SHF, raises several possibilities: a) an additional Harris-Salter V type lesion left undetected, if the fracture was reduced anatomically; b) a malunion in a position with 2-3 elementary displacements from which the gap and the position in varus or valgus of the distal fragment are not missing; c) a hypertrophic callus with medial or lateral hemiepiphysiodesis effect or d) transphyseal fractures.

Remote evaluation of patients with SHF reveals cases with varus elbow, although for a period of time no patient showed this deformity [27]. The optimal time to correct the varus or valgus deformity must take into account the risk of recurrence, if the operation is performed during the growing period. The appearance of growth cartilage on X-ray or MRI is edifying. If necessary, it must be compared with the one on the opposite side. The normal appearance shows that the osteotomy can be done during the growth period, and in case of differentiation, it is better to postpone the intervention later. Correction of axial deviations during periods of growth is done by osteotomies.

In 8 patients out of 13 the growth cartilage was affected or embedded in the callus and the osteotomy followed by fixation was performed after the growth period, and in the other 5 patients the operation was performed during the growth period.

Fixing in "double X" has the same effectiveness. Kasse also uses this method in corrective osteotomies and finds that cross-fixation of the lateral humeral valgus osteotomy is an excellent method in the treatment of post-traumatic varus elbow. Its technical implementation requires good preoperative planning. It gives the elbow an acceptable aesthetic appearance, and complications are generally minor and rare [28].

3. Results and complications

The duration of hospitalization was variable, between 2 and 7 days, depending on the type of fracture, the complication treated and the social situation of some patients.

A first evaluation was done 2 weeks after the operation. In rare and particular cases, the recovery of flexion movements varied in 40-60° and of extension movements in 40-55° (Table 2). In cases of correction of complications, at 14 days the flexion was recovered between 20-45° and the extension between 20-50°.

Table 2 – Elbow mobility after 14 days from "double X" fixation

Results for flexion movements at 14 days	SHFs rare and particular	SHFs with complications, operated	Results for extension movements at 14 days	SHFs rare and particular	SHFs with complications, operated
20° of flexion	0	5	20° of extension	0	6
30° of flexion	0	8	30° of extension	0	2
40° of flexion	4	6	40° of extension	5	11
45° of flexion	7	3	45° of extension	7	2
50° of flexion	9	0	50° of extension	18	1
55° of flexion	6	0	55° of extension	1	0
60° of flexion	5	0	60° of extension	0	0

Data from statistics made by A. Breha and cases treated by Gh. Burnei

The use of fixation methods followed by immobilization in a plaster cast requires maintenance for 2-4 weeks. The total recovery of flexion and extension movements depends on age, type of fracture or complication treated.

At 30 days, 37 patients were recovered, at 35 days 41, and at 45 days 44 (Table 3). In 6 patients, recovery of movements was obtained between the 3rd and 6th month. After 4 years, 2 patients were left with decreased elbow mobility, flexion was limited by 30/40 °, and extension by 25/20 °. Increased recovery time over 30 days and limited mobility occurred in patients operated on 3 or 4 times and in children with elbow stiffness.

Table 3 – Integral recovery of flexion/extension movements of the elbow

Duration	No. of days/months	Observations
At 25 days	12	---
At 30 days	25	---
At 35 days	4	All cases, after 2-3 operations
At 45 days	4	2 cases after 3 operations and 2 cases with elbow stiffness
Between 3-6 months	6	All cases with elbow stiffness
Without integral recovery	2	1 case after 4 operations and 1 case with elbow stiffness
Total	53	

Data from statistics made by A. Breha and cases treated by Gh. Burnei

In medical practice, doctors are especially interested in recovering the mobility of the elbow and avoiding complications. At 2 weeks postoperatively on the occasion of the first check-up, we registered 3 minor complications. These patients had a lower degree of recovery from flexion and extension, and the duration of recovery was in one patient of 30 days and in two patients of 35 days. The 3 complications consisted in the partial externalization of the pins on the 10th day in 2 patients and the presence of the pins in the olecranon fossa in a patient operated by CRPP.

We found 2 major complications that consisted in not fully recovering flexion and extension after elbow reconstruction in 2 patients with elbow stiffness.

4. Discussions

4.1 Therapeutic options in common forms

We encounter rare and particular SHF, in medical practice and in some cases, we can apply the treatment used in common forms. The use of

current therapeutic methods should be analyzed in concrete terms to avoid their failure and the occurrence of complications.

4.1.1 Orthopedic reduction and immobilization in a cast may be an independent therapeutic method or may precede surgical treatment. The choice of treatment is guided by the Gartland classification. In type I extension fractures, after the correct neurovascular examination and evaluation, and in their absence, we opted for a closed reduction followed by immobilization in a plaster splint with the elbow flexed at 90 degrees for 3-4 weeks. Within 7-14 days of treatment, radiological control is performed to rule out loss of reduction. For the success of the orthopedic reduction, some fundamental principles must be fulfilled: 1. the reduction must be made as early as possible; 2. to be performed under general anesthesia to ensure muscle relaxation; 3. the maneuvers for reduction to be made according to the displacement of the distal fragment and 4. adequate immobilization. Failure to do so may be another cause of irreducibility and loss of reduction. Muscle relaxation under general anesthesia gives a success rate of orthopedic reduction of about 83%, while in cases without relaxation the rate is about 56% [29]. The success of orthopedic reduction consists in healing the fracture and functional recovery of the elbow without any other therapeutic procedure. Of these closed reductions, approximately 77% of fractures maintain the alignment of the reduction and do not require surgical treatment [29].

In Gartland type II extension fractures, there has been some controversy about the therapeutic attitude related to the degree of displacement. When the displacement is not large, closed reduction is practiced followed by joint immobilization at 90 degrees [30][31]. Treatment by closed reduction and immobilization of type IIa fractures is done by selection. Hourglass angle and perpendicular distance (PD) from the anterior humeral line to the capitellum are the essential parameters used to verify the reduction efficiency. Success rate is high if reduction is done under anesthesia [29]. Conservative management is recommended for non- or minimally displaced fractures, while there appears to be a trend toward surgery for all displaced fractures. The overall rate of complications after CRPP in type III fractures is approximately 8% [32].

4.1.2 CRPP in a cross or lateral configuration [17] is the standard treatment and at the same time treatment options preferred by most surgeons for grade II and III supracondylar fractures with operative indication [16][33-35]. After blind percutaneous pinning, satisfactory results are obtained in 98% of cases. Vascular and neuronal complications are minor and Volkmann's syndrome does not occur [36]. The results obtained after treatment of grade II fractures by closed reduction and K-wire fixation are better compared to non- fixation reduction. Complication rate is extremely low and secondary operations have dropped considerably to 0.5% [37]. Intraoperative fluoroscopic control improves functional results to good and excellent in 98% of cases. It is always safer to use K-wires to maintain the reduction if the flexion immobilization needs to be greater than 90 degrees to maintain the reduced fracture. When the immobilization is done at over 90 degrees of flexion, there is a risk of compartment syndrome [38]. Some authors prefer in practice the technique of reduction followed by percutaneous pining with K-wires, because in this way they avoid possible associated neurovascular risks and loss of reduction. In Gartland III extension fractures, there is no doubt that the most accepted management in the field is the practice of a closed reduction [17][39][40], whenever possible, followed by stabilization with K-crossed or side wires, depending on the preferences of the surgeon.

4.2 Therapeutic options in rare forms

To avoid the occurrence of a complication, the surgeon prefers a method, considered by others, but also by him, safe and effective at least acceptable and with reduced risk in terms of complication rate. For these rare forms orthopedic

treatment or CRPP have an increased risk of complications. ORIF and cross-fixation provide good stability in rare and particular forms: dysplastic pathologies due to malnutrition, chronic diseases such as celiac disease [41] or other diseases with bone fragility: Albers Schönberg disease or renal dystrophy. The double cross fixation provides the best stability for an anatomical reduction (Fig. 3).

Fig. 3

Supracondylar humerus fracture in a child with celiac disease aged 3 years and 8 months. The diagnosis of celiac disease was established after the mother stated that the fracture occurred after a minor trauma and she is afraid of having fragile bones. Osteogenesis imperfecta was refuted by genetic testing, and the immunological study of osteoprotegerine on the background of a chronic diarrhea established the diagnosis of celiac disease. **A.** At 8 days after the orthopedic reduction, the radiograph showed loss of reduction; **B.** Intraoperatively, the rigorous dissection revealed a bone maceration with multiple bone particles on the lateral pylon. The reduction test outlined a bone defect on the lateral pylon; **C.** The oblique trajectory of the fracture on the lateral pylon had an antero-posterior direction, and on the medial pylon, postero-anterior direction. The reconstruction of the olecranon fossa was done on digital forceps; **D.** Bone defect of the lateral pylon on the present radiograph; **E.** Profile configuration after reduction; **F.** At 7 days elbow flexion, partially possible, allows the patient to flex his hand to his nose.

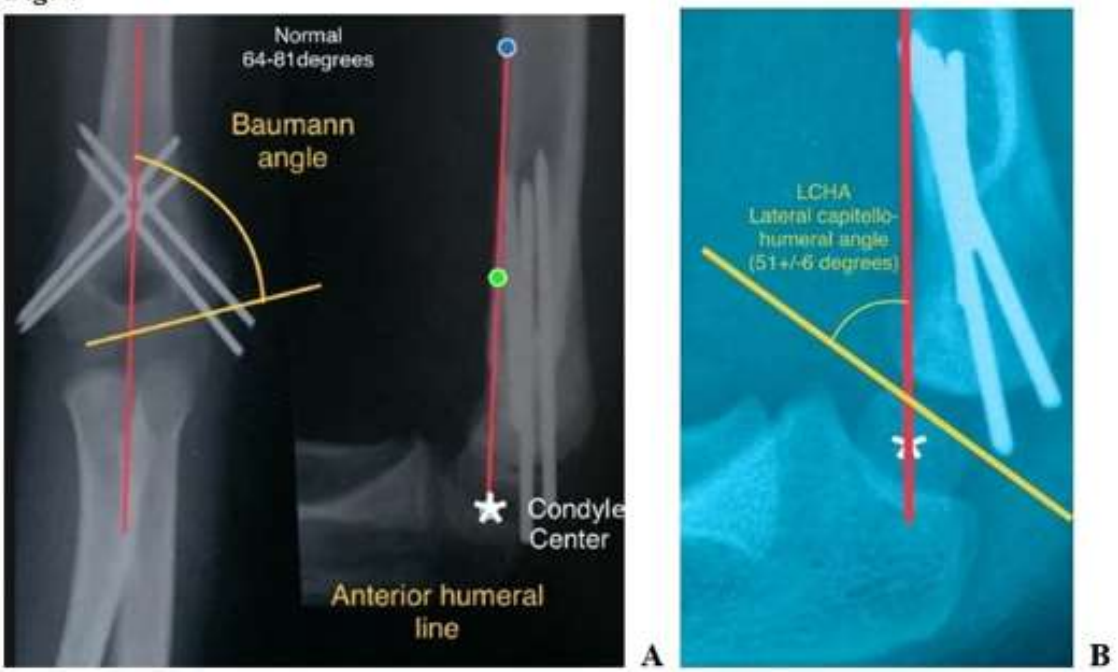
4.3 Clinical evaluations

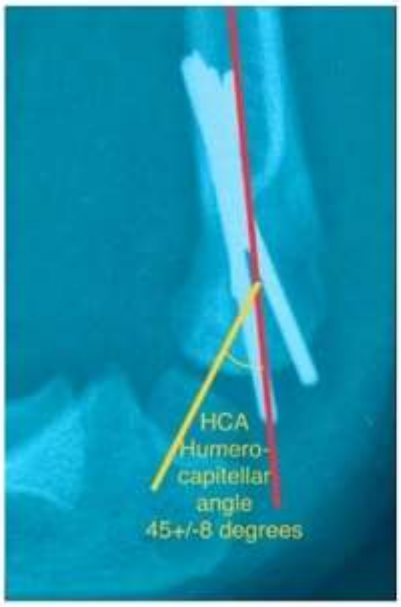
Neurological complications occur in 20-30% of cases. The most common are lesions of the ventral branch of the median nerve. In over 80% of cases it does not require treatment and complete functional recovery occurs within a few months [42]. These neurological deficits may occur due to the fracture itself (direct contusion, tissue edema) or after treatment (during reduction maneuvers, elbow hyperflexion, or K-wires placement). Due to the anatomical region in which these fractures appear, the supracondylar region, the nerves that we can find affected are: median, radial and ulnar. In older articles, median or radial nerve were most commonly affected [43]. Vascular complications, on the other hand, have a lower incidence than neurological ones, but have a much greater impact. Quick and complete diagnosis is essential to avoid "vasa nervorum" type lesions and consequently a serious and devastating injury, such as Volkmann's syndrome.

4.4 Radiological evaluations and their importance

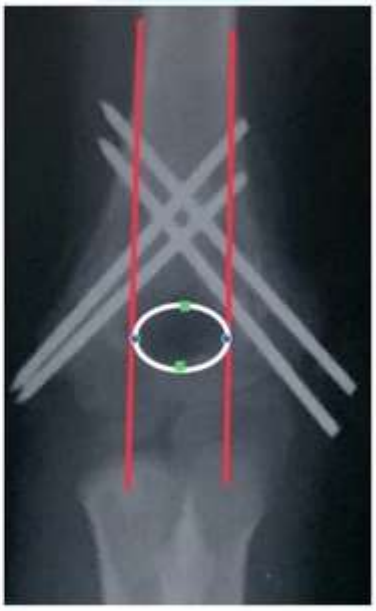
The evaluation criteria to establish the quality of the reduction are BA, AHL, lateral condylo- humeral angle (LCHA), humero-capitellar angle (HCA) and the presence of the olecranon fossa in shape and dimensions (Fig. 4).

Fig. 4





C



D

The evaluation criteria to establish the quality of the reduction. **A.** Baumann angle (BA) has normal values between 64 and 81 degrees. Also known as the humeral-capitellar angle (HCA) is formed by a line passing through the axis of the humerus and a line passing through the epiphyseal plate of the capitellum. It is good to be evaluated compared to the BA on the contralateral side. A difference of more than 5 degrees between the two parts is abnormal. BA increases in residual varus and in deformities by internal rotation. The anterior humeral line (AHL) defines the relationship with the humerus and passes through its center; **B.** Lateral capitello-humeral angle (LCHA) is formed by AHL and the line passing through capitellar physis. It has normal values between 51 +\- 6 degrees and does not vary significantly depending on age or sex. Values lower than 39 degrees and higher than 63 degrees define residual deformities or erroneous measurements; **C.** Humerocapitellar angle (HCA) is the angle formed by the axis of the humeral shaft and the axis of the capitellum on a profile image of the elbow joint. It has a size of 45 +/- 8 degrees; **D.** Olecranon fossa is projected between the two lines that extend the medial and lateral cortex in the area of maximum radiolucency of the humeral palette. The 4 points arranged medially, laterally, proximally and distally are placed at the border between opaque and transparent. The elliptical area has homogeneous transparency. It is easier to spot in children under 9 years old. With the appearance and development of the olecranon nucleus, radiolucency is less obvious. Dimensions are variable with age and symmetrical hemiellipses.

The angle of wear (attitude in varus or valgus of the elbow) is evaluated on front radiograph, in correlation with Baumann's angle. Contralateral elbow radiography is used for comparison, if necessary, because Baumann's angle has variable values in each patient [44].

If BA is not relevant due to the difficulty of identifying the growth cartilage of the humeral condyle, the medial epicondylar epiphyseal angle is determined, recently described as a mean of evaluation in the accuracy of SHF reduction. The average value in children aged 3-12 years is about 38 degrees, with variations between 25-46 degrees [45]. After blind percutaneous pining satisfactory results appear in 98% of cases. Vascular and nervous complications are minor and Volkmann syndrome does not occur [36]. The results improved after percutaneous pinning under fluoroscopic control: in 98% of cases they are good and excellent, and complications decreased.

Postoperative evaluations after ORIF in "double X" showed that there were no changes in BA and AHL, except for oblique fractures and those operated after 14 days in which AHL did not always go through the center of the condyle (7/28). The clinical significance of postoperative radiographs is variable; radiographic examinations may be inadequate for the assessment of lateral LCHA in 13%, BA in 8%, AHL in 2%, rotation in 1% and K-wires fixation in 2% of cases [2]. The K-wires configuration is

the only variable that can be associated with a complication. No association between late follow-up and complications was identified. Routine clinical and radiographic evaluation of displaced SHF requiring CRPP can be performed even when K-wires are removed.

Comparing results obtained by CRPP with those obtained by minimal-open reduction and percutaneous pining (mORPP), showed that in the CRPP group frequently decreases the carrying angle (CA) value. Decreased CA in the operated elbow compared to CA in the unoperated elbow was higher in children operated by CRPP. Children operated by mORPP showed minimal and insignificant changes. The minimal medial-approach (mMA) (differentiated from the epitrochlear minimal-approach) allows better repositioning and eliminates the possibility of varus deformity. The optimal procedure for SHF is mORPP [46].

We used three criteria in evaluating the results after fixing in "double X" to determine the adequacy of the reduction: BA, the relationship of the capitellum with the AHL and the anatomical reconfiguration of the olecranon fossa. The anatomical restoration of the olecranon fossa is the most accurate criteria for the complete recovery of elbow mobility. It must be similar to the configuration on the opposite side. Regardless of the K-wires configuration (the "double X" configuration was also not considered), postoperative BA is normal in only 66% of fractures, AHL crossed the capitellum in 84% and no malrotation was evident in 85% of the fractures. Crossed K-wires were used in 89% of the cases [2].

4.5 Choice of configuration: findings and opinions

A medial K-wire pinning has an increased risk of ulnar nerve injury, and lateral fixation has a high risk of median nerve injury. Some surgeons recommend giving up the medial fixation to avoid injury to the ulnar nerve and recommend the use of 2-3 lateral K-wires [34]. If the stability of the medial pylon after a lateral fixation is tested in the operating room, there can be observed a clear instability of it. In this situation, the placement of a medial K-wire is considered and damage to the ulnar nerve should be avoided. The clinical and radiological examination takes into account the type of fracture, K-wires configuration to fix the fracture as well as the possible risk of injury to the ulnar nerve. Some authors prefer pinning K- wires only in the lateral configuration to prevent iatrogenic lesions of the ulnar nerve. Based on their findings, they do not recommend the routine use of cross configurations in SHF. If a medial K-wire is used, the elbow should not be hyperflexed during its insertion to reduce the incidence of ulnar nerve damage [33].

The epitrochlear approach (EA) eliminates this risk especially in CRPP. After highlighting the medial condyle and locating the K-wire entry point, the fixation of the forearm in hyperflexion ensures the reduction of the fracture and a good fixation of the medial pylon. Other studies that looked at the risk of ulnar nerve lesions on consecutive series of Gartand II and III type SHFs [47][48] treated by placing crossed K-wires using mORPP approach, reported only one case with transient sensory deficit (1/65) and no ulnar nerve motor deficit at 4-5 months. Cross-configuration can be performed safely and is a suitable treatment option for unstable SHF [47]. Intraoperative stability after fixation convinces the surgeon of the strength of the assembly. Coronary and lateral plane check is done fluoroscopically to ascertain the exact location in the planes. Easy mobilization should not cause the fixed fracture to move. In lateral fixation with K-wires, external rotation, lateral translation, posterior translation and valgus stresses led to deformation of the configuration [49]. Double crossing increases stability. The intraoperative evaluation of the “double X” configuration through external and internal rotation, flexion-extension and translation, convinces the surgeon of the firmness of the assembly and of the fact that plaster immobilization can be excluded.

4.6 Principles, trends and results

CRPP in a cross or lateral configuration is the standard treatment for SHF [35]. The major desideratum of the operative act is the reduction and a solid anatomical fixation of the fracture

regardless of the method used, CRPP or ORIF. If the accuracy and quality of the operative act are impeccable, the postoperative evolution is devoid of signs or symptoms specific to surgical aggression. Postoperative radiography does not change the treatment [2] and the result is the desired one.

Both at hospitalization and in the operating room, we must diagnose or rule out the presence of vascular and nervous lesions. Neurovascular complications have a frequency of 35% in closed SHFs and 23% in open ones [4]. A patient with a weak or absent pulse first needs an emergency reduction, not an arteriogram [38]. The quality of postoperative condition depends on the quality of the reduction and the solidity of the fixation. After correct open reductions or percutaneous pining reductions, there is rarely secondary displacement that requires the resumption of closed or open reduction and fixation. Postoperative reassessment requires resumption in only 1% of cases [50].

The quality of K-wire pinning in displaced SHFs in children has not been evaluated and the value of radiographic examinations after their fixation is not conclusive [2]. To avoid posterior placement of K- wires and maintaining the humeral palette in retroversion and medial rotation, K-wires should be placed centrally on the fluoroscopic profile image of the epiphysis and anchored on the opposite cortex [51]. CRPP is believed to be a safe, reliable and effective method [52]. Residual deformities, mild and moderate, present in the sagittal plane in nonoperatively or operatively treated type II fractures have an overall incidence of 10%. The recovery rate of elbow mobility is satisfactory in 91% of cases with residual deformities and 93% in those without [53]. In patients who lost the reduction after percutaneous pining, 84% of them obtained good and excellent results according to Flynn's criteria, without an appreciable difference between open or closed fractures [4]. In comparison with other therapeutic methods, "double X" pinning is an alternative, relatively simple method that provides safety and allows rapid recovery of mobility [54]. The method requires skill and experience.

5. Annotations and observations

Theoretical notions and medical practice are very important in avoiding complications that may occur. Some of them are formidable complications and can induce physical and mental disabilities. KE Wilkins' studies, publications and courses are known to all pediatric orthopedists. His valuable contributions have elucidated many diagnostic and treatment issues and provided practitioners with criteria for therapeutic attitudes. The lectures about PSHF had that spark that ordered the knowledge in this field and medical practice became much simpler. VE Gomez-Palacio in papers like “Review and update of the treatment of humeral supracondylar fractures in childhood” and “Complications in humeral supracondylar fractures in childhood” has presented quasi-exhaustive the PSHF.

These things are the current foundation of notions useful to all specialists. Significant contributions in the diagnosis and treatment of PSHF were made by JJ Gartland, JC Flynn, P Moroz, DL Skagss, V Gil-Albarova, J Weinberg, Molina Mata, F Eguia, A Herrera, AN Kasse and others. Starting with 2001, I applied the method of osteosynthesis in "double X" when the fixation in "X" was precarious.

Most of the cases, 85 out of 94, were studied by A Breha and O Moroi in the bachelor's theses. For a deeper analysis of these cases to which is added a biomechanical study on the resistance of PSHF after various fixation techniques was designed in a project for a PhD.

The negligence and lack of understanding of this project by the PhD student caused the topic to be abandoned and, in a certain context, to prefer congenital scoliosis study, the topic devoid of substance for such a candidate and for a commission whose members have never treated a case of congenital scoliosis. Such papers are useless and must be rejected or canceled by the Higher Commission for PhD Studies.

In Romania, important contributions in PSHF were brought by A Pesamosca, M Socolescu, T Zamfir, Z Moldovan, V Stan, C Tica, A Mironesu, V Cristea and L Muntean.

6. Conclusions

In rare forms the orthopedic reduction is applied with caution. The treatment applied similarly to the frequent cases is followed by the resumption of the reduction and CRPP or ORIF.

CRPP is indicated when the fracture is reduced anatomically or "acceptable" and can be maintained in this position to ensure stability by percutaneous pinning in a cross configuration: San Diego, Dorgan, or Burnei, in “X” or “double X”.

ORIF and the configuration of K-wires in “double X” provide a good stability that the surgeon can be convinced of intraoperatively and which ensures the possibility of rapid recovery.

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