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"Double X" Cross Fixationin Paediatric Supracondylar Humerus Fractures: A 20-Year Expertise and 94 Surgical Interventions

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Supracondylar humerus fractures; Classification, "Double X" fixing; Other therapeutic methods

1. Abstract

1.1. Background Context: Over the last 50 years, the developments emerged in the diagnosis and treatment of supracondylar humerus fractures (SHF) have significantly reduced the number of severe complications while certain complications with dreadful evolution, such as elbow stiffness or Volkmann's syndrome, have completely vanished. During my residency, in 1982, on the suggestion of Prof. Pesamosca, I have performed a surgical intervention for a patient diagnosed with SHF. At that time, the PP with K -wires were placed in an inverted V. The most common complication was the loss of reduction and the consequences seen in many cases were cubitus varus, cubitus valgum, abchilosis or stiffness. The inverted V-fixation was taken from Prof. Vereanu. I asked his permission to cross K-wires and he agreed. It was the first X-fixation. I showed Prof. Vereanu the x-rays and we followed-up the patient together. We found an improvement in the patient's postoperative evolution.

Look! There you are?! the professor asked me after we have noticed the healing and the recovery of the elbow mobility much faster than after other treatment methods. This fixation is more stable as it crosses the opposite cortex. It's a small step forward! This is how we will gradually push the paediatric orthopaedics cart further and further. And this is how X- fixing procedure began to be practiced more frequently.

Starting with 2001, we applied the "double X" osteosynthesis technique to a number of cases where the quality of reduction, intraoperatively verified, was poor or unsatisfactory.

Orthopaedic reduction, percutaneous pining (PP) or Open Reduction and External Fixation (ORIF) by using a certain optimal configuration, are some techniques which have been addressed by many surgeons. Different configurations were used, each coming with certain advantages and disadvantages, as well. Often, the surgeon's preferences are relevant. Radiological and biomechanical studies, the length of the healing process and the functional recovery of the elbow, the capacity to reshape the rotational defects and the occurrence of postoperative complications have guided the therapeutic actions to the use of certain method (s).

1.2. Purpose: The purpose of this paper is to outline the expertise I have gained after completing 240 surgical interventions from 1982 to 2020, in children diagnosed with SHF and whose ages varied from 3 to 14 years; in 94 patients out of the total of 240, (representing 39% of the cases), the fracture was fixed by K-wires

undergoing a "double X" configuration. The opinions of other authors about the results obtained by fixing the fractures in cross configurations such as San Diego, "X" and "double X" are also mentioned here.

1.3. Study Design: This is a retrospective study. The 94 cases referred in this paper have been subject to surgical interventions conducted from 2001 to 2020 and they all include data on the cases I have operated as well as essential details collected by Breha A (50 cases) and Moroi-Manea O (35 cases) who have also prepared bachelor's degree theses for the title of Bachelor of Science in Medicine (MD). In 2013, on the opportunity of the 32nd EPOS Annual Meeting, I presented 56 cases I had operated from 2001 to 2011; and starting from 2012 until the current year, 2020, I have successfully operated another 38 cases.

1.4. Patient Sample: The surgical interventions were performed in public and private hospitals as well. A special emphasis was given to the details presenting the patients for whom "double X" fixation by either PP or ORIF was completed. Many of the patients who underwent the surgical procedures came late due to negligence or due to loss of gypsum reduction induced by oblique fracture trajectory or due to other causes that had not been preoperatively detected.

1.5. Methods: In the cases for which open surgical procedures were performed, we conducted internal fixations by K-wires, according to various techniques: 2 X-pins technique, Judet technique involving 2 parallel pins, San Antonio technique with 3 parallel pins, San Diego technique with 3 pins (2 pins arranged in V or laterally placed while the other was medially put) and the "double X" technique involving 4 pins. An adequate attitude, adapted to each and every case, may always avoid the occurrence of both the minor and major complications which may result in axial deviations, vicious calluses, joint stiffness.

1.6. Results: No severe complications occurred after ORIF. Nevertheless, I noticed two cases of transient radial nerve paresis and a case involving elbow stiffness after PP in a child diagnosed with ossifying myositis, where I personally expected this complication due to the primary diseases. In ossifying myositis all fractures adjacent to joints are basically followed by stiffness.

1.7. Conclusions: "double X" fixing provides an optimal immobilization in cases where extensive bone damage induces extreme instability.

1.8. Significance: The firmness is verifiable intraoperatively and the healing and recovery of flexion and extension occur in no more than 45 days.

2. Introduction

SHFs are located in the distal humeral metaphysis. They are the most common traumatic injuries of the elbow and therefore they occupy the second place in the fractures of the thoracic limbs, after the forearm fractures. They account for over 15% pediatric fractures [1] and ⅔ of elbow fractures [2], more frequently occurring in children aged 3 to 6 years' old. As the open injuries are rare, they are more likely to occur in older boys [3].

The large number of complications that may occur in the pre-therapeutic and post- therapeutic periods has determined the surgeons to pay a special attention in terms of taking the appropriate measures in order to avoid these complications, as well as to choose safer methods of fixation for the fractures that needed surgical interventions and to correct the inherent complications. Consequently, these aspects have been addressed by almost all papers and studies that have been published in this regard.

3. Classification

The most widely used classification of SHF is the classification put forth by Gartland [4]. It is a classification that addresses the movement of the distal fragment and it is designed to establish the therapeutic instructions. The changes brought to the Garland classification do not affect the author's contribution. They make the classification more comprehensive and help the surgeon by bringing more useful details. The original paper grouped these fractures into 3 types:

- Type 1 fractures. Non-displaced fractures (<2mm). The anterior humeral line (AHL) passes through the centre of the capitellum. The fragments remain in contact due to the integrity of the periosteum.
- Type II fractures. Moderate displacement fractures (> 2 mm). AHL passes in front of the centre of the capitellum; the posterior periosteum is intact, but the fracture acts as a hinge.
- Type III fractures. Fractures with complete displacement. This type of fracture is more unstable, with extensive lesions in the soft tissues and periosteum; the facture has an increased incidence of neurovascular damage.

In 1984, Wilkins [5] divided the type ll fractures into lla and llb classes according to the absence (IIA) or presence (IIB) of the malrotation.

In light of certain general criteria, Camp et al. [6] classified the SFH as follows:

a) Fractures involving or lacking displacement.
b) Open or closed fractures
c) Uncomplicated or complicated fractures with or without neurological and / or vascular damage.
d) Extension-fracture (95-98%) or flexion - fracture (2-5%) types.
e) Fractures included in the modified Gartland classification system [7]

Type I fracture: not displaced fractures.

Type II fracture: angulated displaced fractures but which are however maintained in contact by the posterior cortex which is intact.

Fracture II A: Angulation. Basically these fractures are treated by closed reduction and immobilization. Failure or loss of reduction occurs in an attempt to improve and maintain Hourglass Angle (HGA) and Perpendicular Distance (PD) from the anterior humeral line to the capitellum [8].

Fracture II B: Rotational angulation. Following an increasing trend, type II fractures are treated surgically; reduction and immobilization are basically reserved only for fractures with extension displacement. Current management concepts include data on pin placement, pulseless hand issues, compartment syndrome and rotational instability [9].

Type III fracture: involving a complete displacement and no significant cortical contact, and having an intact medial or lateral periosteal hinge.

Fracture III A: Medial periosteal hinge intact. The distal fragment moves postero- medially.

Fracture III B: Intact periosteal lateral hinge. The distal fragment moves posterolaterally. In the literature, the association of radial nerve injuries with type IIIA Gartland fractures, median nerve injuries with type IIIB Gartland fractures and ulnar nerve injuries with flexion fractures is described [10].

Type IV fracture: these fractures lack the periosteal hinge and are unstable both in flexion and extension, i.e. they have multidirectional instability. In 2006, Leitch et al. [11] presented type IV fracture as a fracture that may only be diagnosed intraoperatively. The periosteum is completely ruptured, leading to high fracture instability in both flexion and extension. Multidirectional instability of type IV fractures may be caused by the injury itself or by failed attempts to reduce the fracture.

4. Orthopaedic reduction

SHF treatment in some cases poses difficult problems [12]. A perfect orthopaedic reduction is not always easy to obtain particularly due to the distal fragment which is small and difficult to handle. This inconvenience occurs simultaneously with the emergence of oedema and hematoma which increase progressively, especially 6 hours after the incident. On the other hand, the reduction obtained may be easily lost due to the small support surface of the two fragments of the humeral palett. All these aspects are complemented by a relative assessment of cubitus varus or valgus deviation, translation or lag; the fluoroscopic check-up performed immediately after the orthopaedic reduction and immobilization in the plaster splint does not allow an accurate assessment of these details. This explains the increased rate of complications and the orientation of surgeons towards surgical interventions; orthopaedic reduction and PP, the open mini-reduction and PP or ORIF.

5. Resuming The Reduction

The resumption of the reduction may be done during the first 14 days after the fracture. During this period, the callus is soft and the professionals adopting this orthopedic treatment prefer in some cases to resume the reduction, especially at the express request of parents who prefer the orthopedic treatment. The reduction may be resumed 24-48 hours after the first reduction to correct the position of extensions or malrotation of the humeral palette. Attempting to correct translation or rotation may turn fracture-extension into fracture-flexion and therefore, this process may amplify the instability [13]. Consequently, it is advisable that the correction of these components be done within 7-10 days in order to benefit from the "elasticity" of the callus [14].

6. Percutaneous Pining

"Double X" fixation of SHF via PP results in a robust synthesis that allows mobilization during the first postoperative days. The cross-K-wires configuration is biomechanically superior to the lateral ones in the experimental models [15] [16].

The risk of ulnar nerve damage when fixing the fracture in "double X" occurs only when placing K wires through PP. The incidence of ulnar neuropathy reaches 4% when the elbow is not in extension and 11% when the elbow is in flexion. The ulnar canal decreases in size when the elbow is flexed [17].

The nevus injury may occur directly by nerve ignipuncture or indirectly by contusion or compression. To avoid damages to the ulnar nerve, the surgeon may perform a 2-3 cm mini incision centred on the medial epicondyle (Figure 1)

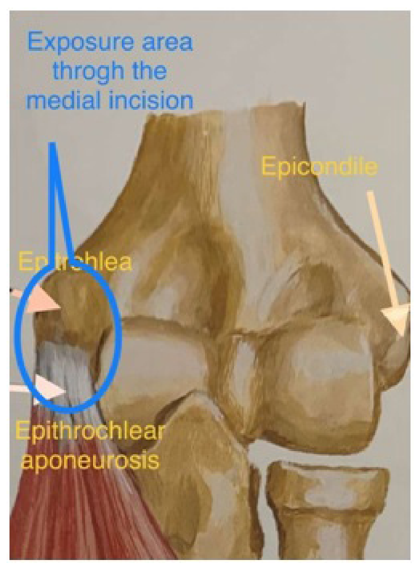


Figure 1: The epithrochlear mini-approach exposes the epitrochlear “bulb”, the epithrochlear aponeurosis and allows the ulnar nerve to be highlighted in order to avoid its damage.

Therefore, the ulnar nerve may be easily identified and isolated. An ultrasonic neurostimulator [18] or probe [19] may also be used to avoid injury. Their position and axis pinpoint the nerve and K-wires are therefore placed in the anterior and parallel plane.

7. Open Reduction

7.1. Indications for the Open Reduction

Conceptually, we always opt for the closed treatment of SHF. Reduction and PP are given priority and ORIF is considered only after the failure thereof [20]. When there is a risk of losing the reduction after immobilization in the casted splint or PP, the surgeon chooses the open reduction as a safety measure. There are few references to the loss of the reduction after the closed reduction and PP. Reduction and PP do not always provide a stable fixation. Postoperative loss of reduction and malunion occur more frequently in closed fractures. Reduction deficiencies are compensated only in 84% of cases [21]. The lateral configuration with the two K-wires in the treatment of grade III fractures has an increased risk of secondary displacement [22] [23]. The loss of reduction presents an overall incidence of about 17% [1].

The lateral cross configuration, i.e. the San Diego technique, poses an increased risk of losing reduction by a rate of 2.6% compared to the fixation in lateral configurations [24] or the differences may be insignificant [25]. The different results are the consequence of each surgeon's ability and preferences.

Open reduction is indicated in cases of failure of closed reduction, vascular or neuronal damage, open fractures [26] and imminent compartment syndrome. In case of vascular or nervous complications it is subject to an express indication and it requires open exploration and possibly surgical intervention [27-29]. They may occur as such or in the form of compartment syndrome. In these cases, fixing in "double X" followed by early mobilization brings great benefits.

For the treatment of vascular injury fractures, the American Academy of Orthopaedic Surgeons has developed a document with criteria for use, outlining a 9-point scale for appropriate treatment [30].

The failure of orthopaedic reduction [31] is the unanimously accepted cause as an indisputable indication for surgical intervention. Failure occurs most frequently in cases of soft tissue interposition. Muscle interposition is the first cause of failure and the rate of irreducibility reaches over 46% cases. The brachialis muscle is attached to one of the columns of the humeral palett and the reduction becomes impossible or the surgeon achieves an unstable reduction which moves secondarily under the cast. Where PP cannot be performed, anaesthesia is given and reduction is performed openly; intraoperatively, the muscular interposition may be identified. The interposition of the joint capsule and the periosteum are not so often causes of loss of reduction or refracturing. The joint capsule interposes and induces the operative intervention in 32.7% cases [29].

7.2. Approach

The Kocher-type lateral approach with rigorous and thorough dissection allows a good visualization of the lesions and allowing at the same time a fixation of fractures with K-wires in "double X" [32] simple and efficient. The technique was described by Georgescu [33]. Few additional clarifications may clarify certain aspects related to operating times and technical details. I personally preferred the side approach. The medial, double (lateral and medial) or transolecranian approach was practiced in certain circumstances.

7.2.1. Lateral Approach: The incision starts from the condyle and extends proximally over a 6-8 cm length. At the proximal pole of the wound, the radial nevus is highlighted and isolated on a cord to avoid being damaged.

7.2.1. Preparation of the Proximal Fragment: Initially, the blood hematoma or the formed clots are removed. The proximal fragment, located ventrally in the fractures by extension, is caught with an elastic forceps, it exposed in the wound and various muscle remnants, fibres, clot fragments or bone micro- fragments left on the surface of the fracture are removed to provide the anatomical reduction. In fractures older than 10 days, "peeling" and removal of the newly formed callus is practiced. Attention! A careful intraoperative evaluation may in some cases find the collapse or fragmentary tearing of the medial pillar or both pillars. The medial pillar is more exposed to strong traumatic agents due to its thin nature. In case of lacerations, double cross-fixation

ensures stability and full recovery of flexion and extension.

The proximal fragment, fixed with elastic forceps, is taken by the left hand of the first assistant surgeon and removed ventrally to free the space above the humeral palett. The space adjacent to the humeral palett is then highlighted even more by placing a suitable Langenbeck retractor, at 30-40 degrees in relation to the forearm axis. The forearm is kept in a 120-130 degree flexion by the third assistant surgeon.

7.2.1.2. Preparation of the Distal Fragment: The second phase starts with the rigorous and thorough dissection of the distal fragment. Attention! The release of the distal fragment from the soft parts shall never be done by means of the razor. This dissection is completed using the scalpel in order to avoid the injuries that may be caused by the razor: the tearing of certain metaphyseal fragments involving the occurrence of defects as bone gaps. These may be reflected, as consequences, in the quality of the reduction and they may further lead to vicious consolidations or the appearance of exuberant spurs acting as impingements.

a) At the distal pole of the wound, the capsule is located and opened. The release of the ventral face of the palett is done over the distal to proximal direction. The procedure is similar for releasing the back face of the pallet. Visualization of the olecranon fossa is very useful for fractures located a few millimeters from the growth cartilage. These fractures cross the olecranon fossa and we found them in almost 85% of cases. Its highlighting is mandatory especially in communicative T-fractures, fractures with multiple parts or fractures with multiple small fragments. The release of the two faces of the distal fragment exposes the humero-radio-ulnar joint. Any injuries to the radial neck or olecranon may be minimally invasively treated with "on sight" control.

The fracture trance of the distal fragment frequently has a "margin" formed by the metaphyseal cortex, window-shaped and with easily removable fringes.

7.2.1.3. Preparation of the Medial Pillar: Finally, the medial pillar of the patella is clearly identified and highlighted. We carefully remove the surrounding tissue covering the surface of the medial pillar of the humeral palett and which may be interposed at reduction. The free surfaces of the two faces allow the proof of the anatomical reduction. An optimal dissection and anaesthetic relaxation allow the reduction of the fragments.

7.2.1.4. Double Crossed "Double-X" Pin Fixing Technique: After the fixation stage, the 2 fragments are untied and the pins are inserted in the retrograde-to-anterograde medial pillar or one pin is placed retrograde-to-anterograde and the other is inserted by means of the guide. To complete this movement, 2 ends pins are chosen.

The pins inserted in the pillar of the distal fragment are externalized in the opposite diaphyseal cortex. The insertion of the second brooch is done by means of a guide to ensure parallel and coplanar positioning. The reduction is resumed and the surgeon proceeds to the anterograde merging. The configuration of the humeral palett and the arrangement of the pins, immediately below the cortex of the proximal fragment, prevent the pins from passing through the epitrochleo-olecranon fossa and injuring the ulnar nerve (Figure 2) Position of the tips of the pins on the medial pillar is checked intra-operatively using the left-handed index placed onto the epiltrochlea. The pin is inserted until it feels under the skin then it is carefully retracted until the rotational vibration in the soft parts disappears. Their position may also be checked fluoroscopically.

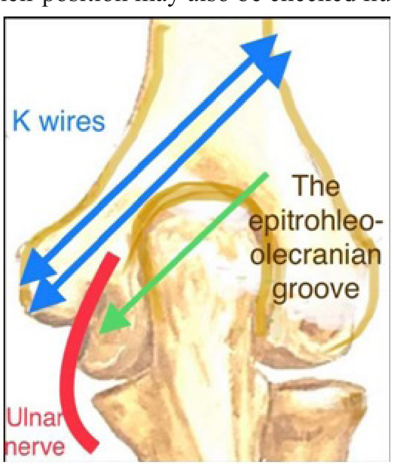


Figure 2: ORIF allows the placement of K-wires inside the medial pillar and their retrograde- anterograde insertion and it has no chance to damage the ulnar nerve.

I did not report any case claiming ulnar nerve paresis. Fixing the ulnar pillar allows checking the flexion, extension and stability of the intraoperative fracture focus. "The thumb- index touch" does not detect the mobility of the medial pillar. However, flexion and extension highlight the mobility of the lateral half of the humeral palett. Fixing the side pillar with two parallel pins achieves a stable double cross configuration with a reconfigured olecranon dimple, free and without the potential to develop an impingement flaw. Postoperative immobilization is not required. After waking up, the children refuse the cast. In relation to the threshold of their sensitivity, a series of children were able to complete written tasks from the 7th to the 10th day postoperatively. On the 7th day many were able to do complete elbow flexion (Figure 3).

The strategy and the technique presented above is particularly useful in children operated after 10 days from the accident, in fact in children for whom a new surgical intervention was decided to be completed from 10 to 60 days as of the time of occurrence of fracture. Once this method has been applied, there will be no need to immobilize the limb in a plaster cast, as the recovery is resumed during the first days, the fracture is healed with a palett in a normal position and the elbow function is fully recovered in 91% of patients.

7.2.2. Medial Approach: It is a useful way of approach in SHF where the collapse of the medial pillar of the humeral palett or the neurological signs of the ulnar nerve are present. This approach individualizes the ulnar nerve in the epitrohleoolecranial groove and where there is any risk that an irritating spine may maintain neuropraxia, it is positioned ventrally to be protected by a "muscle bed". This approach was practiced similarly and with the same thoroughness as the lateral approach. It offers a better visibility of the medial pillar and the possibility to regroup the comminutions and to reconstruct the pillar in its anatomical axis to exclude the elbow's cubitus varus or the limitation of the extension.

Some authors use this preferential approach in cases where closed reduction may not be achieved, in order to avoid damage to the median nerve as well as the cubitus varus [34].

7.2.3. The Trans-Tricipital Posterior Approach requires immobilization and reduces the advantage of early mobilization conferred by the "Double-X" cross-fixing. Approaching the lateral or medial fracture of the brachial triceps tendon allows early mobilization.

7.2.4. The Transolecranian Approach may be followed by the lack of immobilization and it provides an early mobilization, compatible with the "Double-X" fixation if the osteosynthesis in the hob of the olecranon is solid. Although a new T-shaped or cominutive bone lesion is created in SHF, this approach offers comfort and confidence of the surgeon that the reduction and fixation were done "on sight" and safely to ensure the best containment possible.

Figure 3: A 3-year and 4-month-old child fell down from a playground slide and the mother saw the child's elbow inverted in hyperextension with the forearm's dorsal face close to the arm's dorsal face. As an emergency intervention, the medical team performed the orthopedic reduction that yielded the ischemic phenomena. The orthopedic reduction was resumed twice and after 7 days, the imminence of compartment syndrome and the displaced fracture occurred. Surgical intervention was performed through the Kocher approach; the "double-X" ORIF was also practiced: a) Profile image before the intervention where the asymmetric gap and the movement in decubitus varum are presented. b) The face image and c) the profile.
After fixing, gap spaces are visible on both the lateral and the medial pillar; d) Bruises, petechiae and blood sub-fusions disseminated onto the ventral face of the elbow are present 7 days after surgery and 14 days after the accident; e) extension limited by 10 degrees. f) elbow flexion allows the patient to put his hand to his nose 7 days after surgery.

8. Indication on "Double X" Fixation

There are still a series of controversies over what constitutes optimal management of SHF and its complications [35-36]. After determining the srgical indications and the manner to approach the fracture, we proceed to assess the lesions intraoperatively. The K-wires configuration is determined preoperatively, particularly in cases where the biological status is not compatible with another configuration or where there is a hight risk of occrurring devastating complications. The cases where the decision may be made intraoperatively are not excluded. We performed the double -X fixing in the following circumstances:

1. In SHF type III and IV, according to the modified Gartland classification, in patients where the closed reduction and plaster immobilization or PP did not reduce the fracture or the reduction was unstable. In children treated via ORIF and plaster immobilization, the term required for the healing and recovery process may be up to one year [22]. After the "double X" fixation, the recovery of elbow mobility was obtained 30-45 days postoperatively in all patients.

2. In children with polytrauma, in order to facilitate complex care in intensive care and intensive care units.

3. Fractures involving the instability of one of the two pillars (the lateral and / or the medial pillar), or when the fracture path has an obliquity over 10 degrees. Previous studies have shown poor results in the case of internal rotation of the distal fragment or the presence of comminutions on the medial or lateral pillar [37].

4. In children with severe neurological disorders susceptible to spontaneous remission; 13-20% of the neurological lesions occurring in SHF are treated surgically. They may be diagnosed preoperatively, on the operating table under general anaesthesia, by ultrasound evaluation and electrical neurostimulation. "double X" fixing allows the plastic surgeon comfort without the risk of damaging the intervention.

The median nerve lesions that have been preoperatively untreated may later on require the neurolysis of a partially intact clinical and electrical nerve whose activity is improved in terms of motor and sensory capacities [38]. In very young children, paralysis of the median nevus after PP and the association with paresthesias may result in serious consequences. A small child was unable to cope with these paresthesias and self-mutilated by biting his fingers 1-3 [39].

Nerve injuries are more common in closed fractures than in the open fractures (35% and 23%, respectively). Spontaneous recovery of the damages occurred in nerves occurs in 87% cases in 3 to 6 months [21]. Preoperative neurological complications caused by external or internal factors may occur in 5% to 19% of the cases [40-42]. In some cases, their frequency may reach up to 49% [43]. Iatrogenic lesions have an incidence of 2-5% and 80% of them are subject to spontaneous relapse after few months [44-46]. The median and / or radial nerve was/were most commonly affected [47] probably due to an irritating spine caused by the placement of partially extraosseous K-wires through PP. Nerve injuries are more common in closed fractures than in the open ones, 35% and 23%, respectively. Spontaneous recovery of the nerve damage occurs in 87% of cases in 3 to 6 months [21].

5. Presence of acute vascular disorders. The prevalence of signs of ischemia, diminished or absent pulses is 27% in open fractures and 18% in closed fractures [21]. Circulatory failure at presentation has a prevalence of 5% to 17% and it should be managed initially by rapid closed reduction and fixation without arteriography [35].

The strategy of the orthopaedic surgeon in the treatment of pulse-free SHF remains a major challenge in terms of the decision-making process. Pulse-free SHF continues to be a major topic for research and debates due to morbidity, if treated "properly". Therefore, it is highly necessary to continue the research works in this field [48].

Currently, a series of surgeons wait up to 12 to 18 hours after accident to perform surgery, provided that the neurovascular and soft tissue condition allows this delay [49]. When the ischemic syndrome persists after the fracture reduction and immobilization in a plaster cast and the pulse oximeter indicates an oxygen saturation <80 in the first 30 minutes, emergency surgical intervention is highly recommended.

6. T-fractures or comminutive fractures.

7. Children with multiple ipsilateral fractures that require orthopaedic treatment or surgery.

8. Obese children. Supercondylar humerus fractures present in obese children aged 8 to 12 years are more than 4 times more likely to require ORIF compared to children of the same age and normal weight [50].

9. Children with systemic disorders affecting osteogenesis (rickets, imperfect osteogenesis, diseases and malignancies, etc.).

10. Children with therapeutic procedures that may induce the reduction of osteogenesis.

11. Children with mental disorders that do not allow normal monitoring and who are at risk of suffering new fractures (autism, other behavioural disorders, etc.)

12. Children with physical disabilities.

13. In children with open fractures. Once with the timely treatment of wounds and fractures, the clinical and radiographic outcomes of children treated for open SCFs are similar to those with closed type III lesions, with an increased risk of infection, malunion, or neurovascular compromise [21]. To eliminate or reduce these risks in type II, llla and lllb fractures according to the Gustilo-Amderson classification, the wounds were rigorously asepticized and covered with aspiration-based dressing up to the skin plasty.

14. Neglected fractures after 14-60 days as of their occurrence. These fractures evolve spontaneously causing major complications.

15. Grade III recurrent fractures. These are iterative fractures that occur 30 days after healing and which, during their spontaneous evolution, cause the formation of hypertrophic calluses followed by limited mobility or stiffness of the elbow.

16. Bilateral suprondondylar fractures.

17. Unusual fractures very rarely found under the form of pathological tumour fracture or dysplastic bone fracture complex. Distortion of the distal extremity of the humerus and olecranon associated with bone fragility present in Imperfect Osteogenesis facilitate the occurrence of SHF onto a pathological bone in children with limited elbow mobility. Fixing these fractures requires reconstruction and not an anatomical reduction to restore the dysmorphic elbow with limited mobility.

9. Discussions

The ideal configuration of K-wires has always been controversial [51-52]. There are different treatment options for displaced SHF. The surgeon's preference is not excluded either. Over the years, the procedure involving fixing the fragments was done according to several techniques.

Gomez, in 2013, in the article titled "Review and update the treatment of supracondylar humerus fractures in childhood" describes several techniques which he groups in cross- configurations and lateral configurations [22]. In cross configurations, he mentions: a. Cross configuration; b. Double cross configuration, Burnei technique; c. Lateral transverse configuration, Dorgan technique (Figure 4).

The lateral configurations cover: a. Lateral configuration; b. Configuration with three side K- wires, San Antonio technique; c. Configuration with two side and one medial K-wires, San Diego technique, a cross configuration (Figure 5).

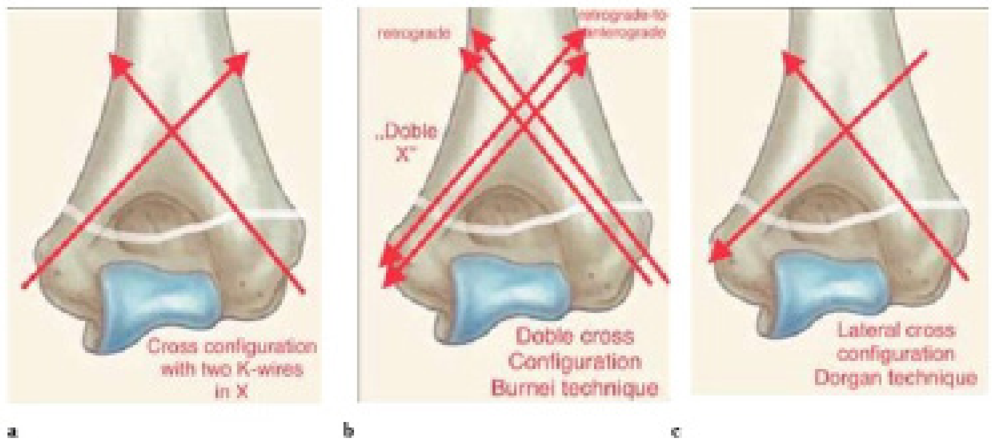


Figure 4: Different configurations for osteosynthesis with Kirschner wires: a) Cross configuration; b) Double cross configuration, Technical office; c) Lateral cross configuration, Dorgan technique (Diagrams according to the Gomez graphic model: Gómez VE, Gil Albarova J, Herrera A. Review and updating of the treatment of humeral supracondylar fractures in childhood. Rev Esp Cir Osteoar. References 22.

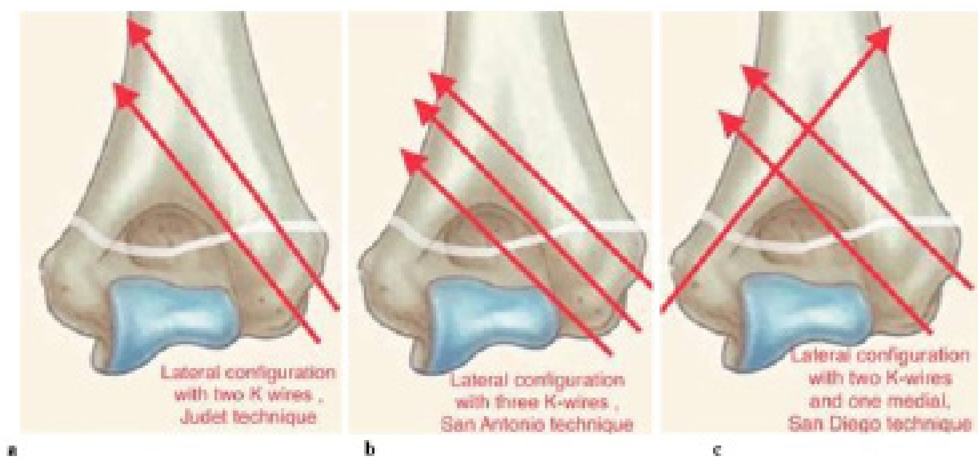


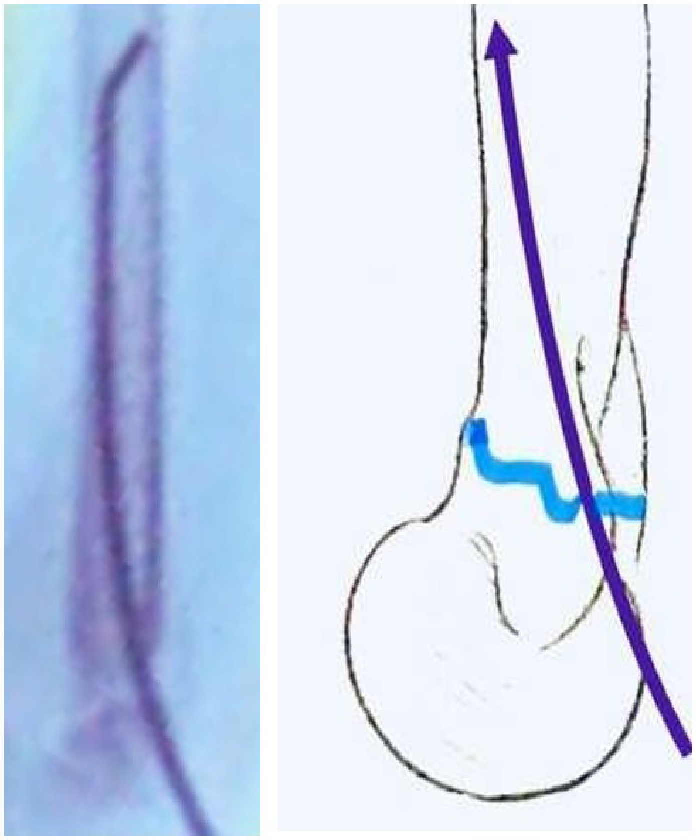
Figure 5: Different configurations for osteosynthesis with Kirschner wires: a) Side configuration;
b) Configuration with three lateral spiers, San Antonio technique; c) Configuration with two lateral needles and one medial, San Diego technique. (Diagrams according to the Gomez
graphic model: Gómez VE, Gil Albarova J, Herrera A. Review and update of the treatment of supracondylar fractures of the humerus in childhood. Rev Esp Cir Osteoar. 2013. References 22.

In different countries in Asia and South America, grade IIB and III fractures, according to the Gartland classification, are treated by closed reduction and percutaneous- trans-focal fixation with K-wire or elastic rods (Figure 6). The technique inspired by Kapandji, is faster, easier to perform, it does not fix the opposite cortex and it does not cause any neurological complications [53-54].

However, there is a controversy about the optimal configuration of K-wires. For some authors is hard to find any differences between the cross and lateral fixation of Gartland III fractures in terms of radiographic appearance after reduction or the complication rates [55].

9.1. “Double-X” Crossed Fixation

In 2014, Molina Mata mentions that a new technique recently described, i.e. Burnei’s “double X” internal fixation technique for supracondylar humerus fractures in children, offers an alternative to fracture fixation [1]. It is recommended that the K-wires should not go through the olecranon or coronoid socket. In relation to the lateral configurations, K-wires placed by various techniques do not exclude this possibility. The safest and most solid fixation on the quality of the configuration is obtained by the closed or open double-crossed fixing completed via a fluoroscopic guide and control. This safety measure is of paramount importance in certain types and forms of SHF, especially when they occur on the background of ceratin comorbidities that foster the occurrence of complications or a completely unfavourable evolution. After applying one K-wires on one pillar, the application of the other becomes a simple formal action. Using the guide enhances the security in terms of positioning it in a plane parallel to the plane of the previous surface. Double X cross-fixation amplifies solidity [51].



a b

Figure 6: a) Fluoroscopic appearance and b) sketch of SHF stabilization via percutaneous- transfocal pining ac

Four K wires are used instead of two, with a cross arrangement, to form a double X. This therapeutic option has the advantage that it does not require additional immobilization and also allows the early initiation of recovery [1]

"X" or "double X" fixation provides sufficient stability to allow early mobilization and recovery of the elbow mobility [33,56]. No secondary displacement was noticed [36]. It is important to note that crossed fixation provides a higher stability [1] Cubitus varum is the most common and delayed complication of these fractures [57,58]. This complication is a result of imperfect reduction and therefore it is not attributable to any growth disorders [59].

By lateral, posterior, or double (lateral and medial) approach followed by double cross-fixation fracture healing, without non-union, malunion, loosening of implant, loss of reduction, Baumann's angle, and shaft condylar angle [60].

In children with SHF, the K-cross wires increase fracture stability compared to the K- wires placed laterally [61]. If X-double crossed K-wires are used, the stability is even better and it allows early mobilization. After 30-45 days, the elbow mobility is fully recovered. The double X configuration ensures good stability even after osteotomies.

X cross-fixation is considered from a biomechanical point of view to be the most stable method and a satisfactory technique for displaced and unstable fractures [62].

The recovery time of elbow joint movements in children aged 1 to 13 years and who have been treated with open reduction and fixation with K-wire and those treated with closed reduction and percutaneous pinning is not statistically significant when both methods are followed by postoperative immobilization in plaster splint [20].

Osteosynthesis with X-crossed K-wires has begun to be widely used in displaced SCF but the rate of secondary displacement is up to 31%. Biomechanical data reveal that K-wires have the highest rigidity and the lowest loss of cyclic loading reductions [63].

The double X configuration, particularly in the open reduction, does not allow the movement of fragments and, at the same time, it is very important in providing stability with no need of immobilization. Pain control in the first 3 days after the surgical intervention and especially on the first day is highly important. A significant pain or the lack thereof, gives children confidence allowing them to ignore the low-intensity pain that is to be felt during the next couple of days. The presence of pain after the 5th postoperative day requires clinical evaluation, possibly radiological assessment. Moderate doses of acetaminophen, ketoprofen and an opioid cut the pain on the first and second day (Dr. Mihaela Banculescu) and the patient actively mobilizes the elbow while the parents support passive mobilization. On the 7th postoperative day, over 65% of children are able to touch the nose with their hand and 4-5 weeks later, 90% of patients fully recover flexion and extension. Breha analysed a group of 50 patients aged 3 to 12 years in whom the fracture was fixed with "double-X" K-wires and found that the total recovery of flexion-extension movements was variable depending on age; basically, the recovery occurred after 25-40 days, on average 29.7 days; 26% in 25 days (13),

56% in 30 days (28), 14% in 35 days (7) and 4% in 40 days (2) [64]. Recovery procedures occurred at home, spontaneously via free active and passive movements, assisted by the parents. With proper parental counselling, satisfactory pain control may be achieved with acetaminophen and ibuprofen for most patients. If oxycodone is prescribed for severe pain, the authors recommend its limitation to less than 6 doses [65].

9.2. Double X Fixing Followed by Cast Immobilization

The application of a X cross-configuration, either via PP or via ORIF is followed by plaster splint immobilization for 3 to 4 weeks. Non-anatomical reductions and loss of reduction are present in both circumstances in variable percentages. Tuomilehto mentions that, postoperatively, after using Cross-K-wires, the Baumann angle is abnormal in 34% of fractures, AHL does not cross the head in 14% of cases and malrotation is present in 15% of fractures [66].

In a study of 139 patients diagnosed with SHF and treated differently with gypsum, traction and percutaneous pining, Young noticed [67]. that the loss of elbow mobility (ankylosis and stiffness) had a higher rate in the PP-treated fractures. The stabilization containment obtained via PP in cross-configuration was followed by immobilization in plaster cast. Secondary displacement more frequent after PP, says Young, and immobilization may result in malnutrition. The transient functional limitation in the elbow joint as a result of immobilization amplifies the loss of mobility induced by malunion.

A number of authors outline the fact that fracture reduction followed by cross-fixation has an increased risk of iatrogenic ulnar nerve damage due to K -wire that goes through the epicondyle. Ulnar nerve damage is estimated to reach 8% [68]. Avoidance of ulnar nerve injury may be done by -a minimal epitrochlear approach when the surgeon has the uncertainty of correct placement of K-wires onto the medial pillar. The risk of loss of mobility by malunion, immobilization, to which is added the possibility of an iatrogenic ulnar nerve injury [69] directs the surgeon to a "Double-X" fixation either via PP with minimally invasive approach on the medial epicondyle if necessary, or via an open approach. Only minor and rare complications may occur [36].

10. Conclusions

"Double-X" PP allows a better fixation of a closed reduction and a rapid mobilization without the need for immobilization in a plaster cast. The risk of ulnar nerve damage may be avoided by a minimal approach on the relief of the epithelium. In order to obtain a better or anatomical reduction after highlighting the epithelium and the nerve, the pining is done with the elbow in flexion and under fluoroscopic control. After X fixing, the insertion of the second pin for each pillar is made simple, safe and fast with the help of the guide.

"Double-X" ORIF provides the strong content of an anatomical reduction. The insertion of K-wires on the retrograde-to-anterograde medial pillar does not present any risk of ulnar nerve damage. Intraoperatively, the surgeon is convinced of the quality of the reduction and fixation by the absence of mobility in the focus to the normal movements of traction, rotation, translation, flexion and extension. "Double X" fixation and early mobilization of the elbow is followed by healing and functional recovery after 30-45 days.

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