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ORIGINAL ARTICLE • UPPER LIMB - PAEDIATRICS

Midterm results of surgical treatment of displaced proximal humeral fractures in children

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Abstract
Purpose To analyse the clinical outcomes of 26 children treated surgically for displaced proximal humerus fracture.
Materials and methods From January 2008 to December 2012, 26 children/adolescents (14 boys, 12 girls) were treated surgically for displaced fractures at the proximal extremity of the humerus. Ten were grade III and 16 were grade IV according to the Neer–Horowitz classification with a mean age of 12.8 ± 4.2 years. Twenty young patients were surgically treated with a closed reduction and direct percutaneous pinning; six required an open approach. To obtain a proper analysis, we compared the Costant scores with the contralateral shoulder (Δ Costant).
Results The mean follow-up period was 34 months (range 10–55). Two grade IV patients showed a loss in the reduction after percutaneous treatment. This required open surgery with a plate and screws. On average, the treated fractures healed at 40 days. The mean Δ Costant score was 8.43 (range 2–22). There was a statistically significant improvement in the mean Δ Costant score in grade III patients. In grade IV patients, there was a significant improvement in the mean Δ Costant score in those treated with open surgery versus mini-invasive surgery.
Conclusions Our study shows excellent results with percutaneous k-wires. This closed surgery had success in these patients, and the excellent outcomes noted here lead us to prefer the mini-invasive surgical approach in NH grade III fractures. In grade IV, the best results were noted in patients treated with open surgery. We suggest an open approach for these patients.
Level of evidence III.

Keywords Humerus · Fracture · Epiphyseal injury · Surgical treatment · Children

Introduction

Proximal humerus fractures in children represent less than 0.5 % of all fractures in paediatric populations and 4–7 % of all epiphyseal injuries [1, 2]; 85 % of these fractures are either undisplaced or only slightly displaced, and only 15 % show severe displacement [3].

The proximal epiphysis of the humerus is completely cartilaginous at birth, and the physis is composed of three ossification centres: the head, the lesser tuberosity, and the greater tuberosity. The primary ossification centre appears at about 4–6 months of age, greater tuberosity appears at 3 years, and the lesser tuberosity appears at 5 years when ossification centres appear. Fusion of the nucleus occurs at about 7 years of age. The growth plate closes completely at about 17 years. The proximal physeal plate accounts for ~80 % of the humeral growth, and this region shows a marked remodelling potential. This concept is the base of treatment for children with proximal humeral fractures [4–6].

Humeral fracture can result from compression, inclination, flexion, shear, and torsion. Shear forces in particular can cause epiphyseal separation, whereas torsion forces produce metaphyseal fractures—especially in adolescents [2]. A physeal growth arrest with a consecutive bone bridge can occasionally occur after an injury of the proximal humerus physis. The length discrepancy or angular

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deformity is the most frequent complication. Management of these fractures—both conservative and operative—may change in relation to age, displacement, and stability. Even a minor displacement is well tolerated in this kind of fracture because of the high regenerative potential of the proximal humeral epiphysis during the growth period [4]. Therefore, most of these fractures—especially the non-displaced ones—are treated by immobilization. Surgical treatment is often suggested in the case of unstable or severely displaced proximal humerus. For surgical treatment, a variety of means are used including K-wires and screws [7]. The most commonly used method is percutaneous K-wires. The aim of this study is to evaluate the outcomes of the displaced proximal humeral fractures in children treated surgically and to assess the clinical results after rehabilitation.

Patients and methods

This was a retrospective study of 26 paediatric patients admitted between January 2008 and December 2012 to the Department of Orthopaedic Surgery and Traumatology of the University of Catania, Italy, for evaluation of proximal humeral fracture. The inclusion criteria included: skeletal immaturity determined by the radiographic presence of the physis, epiphyseal or metaphyseal fractures of the proximal humerus with such a degree of dislocation that the potential of bone remodelling was not sufficient to ensure healing without residual deformity, direct or indirect traumatic mechanism, closed trauma and the absence of exposure, the absence of pathological fractures due to cysts or other causes, and the absence of vascular or neural lesions. Polytraumatized patients or children with other associated fractures were excluded. The data examined for each patient included age, gender, mechanism of injury, type of fracture, type of surgery, and complications. The mean age at time of fracture was 12.8 ± 4.2 years old. In general, 12 patients were females (46.1 %) and 14 were males (53.8 %). The right side was involved in 11 and the left in 15. There were two main traumatic mechanisms: indirect trauma due to a fall with extended, extrarotated, and abducted upper limb (16 patients; 61.5 %) and direct trauma (10 patients; 38.4 %). The trauma causes were sport falls (8 cases), trivial falls (6 patients), bicycle accidents (6 cases), road traumas (4 cases), and 2 falls from a greater height. All fractures were classified according to Neer–Horowitz (NH) classification for the displacement and the Salter–Harris classification for epiphyseal injuries (Table 1).

The Neer–Horowitz classification system is based on displacement severity: grade I, no displacement; grade II, displacement no greater than one-third of the shaft width; grade III, displacement greater than one-third but no greater than two-thirds of the shaft width; and grade IV, displacement greater than two-thirds of the shaft width. In examined group, ten patients (38.5 %) had a NH grade III, while 16 patients (61.5 %) were grade IV. Of the 26 fractures, 20 young patients (76.92 %) were surgically treated with a closed reduction and percutaneous osteosynthesis; six cases (23.08 %) required an open treatment for reduction using a transdeltoid approach (Table 2).

The surgical technique follows the common procedure of direct percutaneous pinning—three percutaneous Kirschner wires (average diameter 2–2.5 mm) were used. The patient was given general anaesthesia in the operating room, and manipulative reduction is performed using manoeuvres that overcome the displacing forces. Two wires are inserted through the greater tuberosity and directed inferior–medial to the humeral shaft through the fracture; a wire was inserted instead in metaphysis in the direction of lateral–medial and caudal–cranial to the humeral head through the fracture. All wires were then resected above the skin, and the shoulder was immobilized with a Desault or Gilchrist bandage. All patients underwent prophylactic antibiotics for 30–60 min before surgery with a first-generation cephalosporin.

Radiographic evaluations in antero-posterior and lateral view were performed at 1, 3, and 6 months after surgery. A Gilchrist bandage was applied for 4 weeks after surgery. In patients who underwent a mini-invasive treatment, the K-wires were removed after 4 weeks of X-ray control. The rehabilitation program started after a mean of 30 days in all patients. Passive mobilization exercises with pendular motion started at 30 days, and the patient started active exercise without any resistance after 35 days. After 45 days, the patient started movements against resistance. We used radiographic controls to evaluate the presence of consolidation, secondary displacement as well as migration, non-unions, or malunions.

Three questionnaire scores were used to assess the shoulder: Costant score, Quick DASH, and sports–recreational activity. All of these were collected at 6 months of follow-up.

The Constant score provides a functional score (maximum score 100 points), which was compared to the score

Table 1 Patients

Number of cases	Male	Female	Age (mean)	Right	Left
26	14 (53.8 %)	12 (46.1 %)	12.8 (± 4.2)	11 (42.3 %)	15 (57.7 %)

Table 2 Patients and questionnaires' scores

Type of fracture	Patients	Closed surgery	Open surgery	Mean Δ Costant score	Mean Quick DASH score	Mean activities score
Grade III	10	10	0	4.39	0.2	0.4
Grade IV	16	10	6	10.96	0.9	1.9
Tot	26	20	6	8.43	0.56	1.32

of the opposite shoulder. This scale assesses the pain, activities of daily living, active mobility, and shoulder strength. The pain is rated from 0 to 15. It is the pain that results from the efforts of everyday life and the degree of subjective pain. The activities of daily living (score 0–20) evaluate the disability at work or daily schedules including disability during exercise and sleep disorders. The force evaluated with respect to the maximum weight lifted with the arm in abduction was maintained at 90° for 5 s; one point was assigned for each 0.5 kg of weight with a maximum score of 25. The active mobility (score 0–40) evaluates the voluntary movement of flexion, abduction, external rotation, and internal rotation [8]. In the Constant score, the result of the difference between the score of the injured shoulder and the score of the contralateral shoulder was evaluated as follows: >30 "poor", 21–30 "fair", 11–20 "good", and <11 "excellent".

Each patient was given the modified Quick DASH questionnaire for paediatric patients. This study tool consists of 30 questions that measure active and passive mobility, activity, strength, and symptoms in patients with any musculoskeletal alteration of the upper limb. The questions refer to the ability to perform some simple actions in the last week. The symptoms occurred while making these movements. The results of the Quick DASH range from 0 (no disability) to 100 (extreme disability) [9].

Simultaneous with the Quick DASH, patients were given the optional "Sports–recreational Activities". This additional form consists of four questions regarding the difficulty in play games and sports. Scores range from 0 (no difficulty) to 100 (extreme difficulty). The score cannot be calculated if the patient does not answer all the questions.

Range of motion of the shoulder was also assessed in all patients at each clinical time point. Data were analysed with SPSS 13. The *T* Test for independent variables was performed to assess variations in the mean of the difference in the Costant score of the injured shoulder with the healthy one among the patients treated with closed and open surgery. We term this difference the "Δ Costant score". This was further analysed with the Mann–Whitney's *U* test. All data are expressed in the form of "mean ± standard deviation".

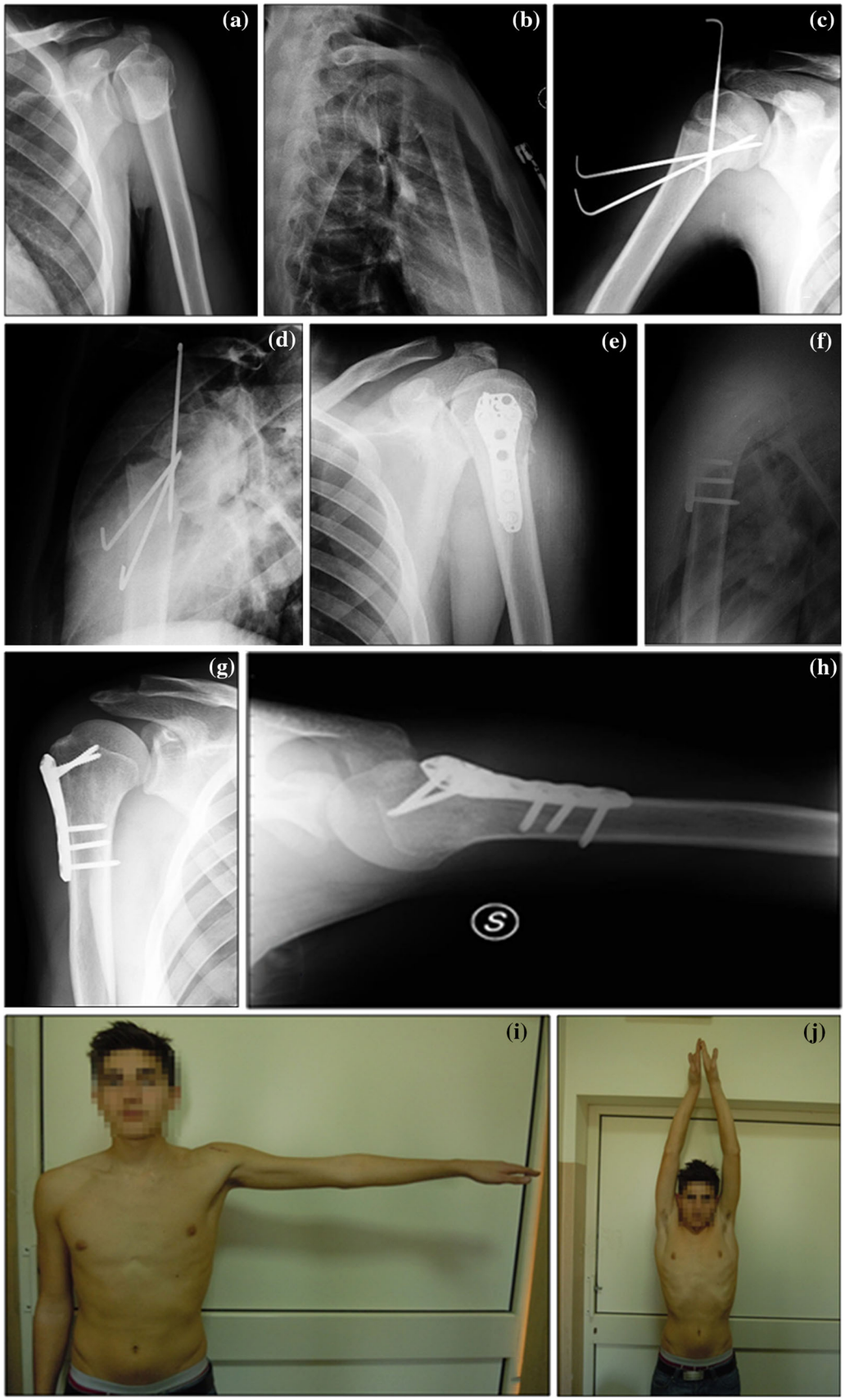
Results

Patients were assessed with a mean follow-up period of 34 months (range 10–55). The mean hospital stay was 3.1 days. The mean surgery time was 28 min. On average, the treated fractures healed for 40 days. At post-operative radiography, all fractures had improved. The fracture angle at this point was NH grade I. No cases showed shortening of the humerus. There were no vascular and neurological complications. There were no cases of post-operative infections, wound breakdown, or pseudoarthrosis. There was no premature closure of the growth plate.

In two patients (12 and 15 years old; both NH grade IV), open surgery was required after 2 weeks for the failure of the mini-invasive treatment. The patients complained of pain and swelling. This made it necessary to surgically remove the K-wires and fix the fracture with a plate and screws, which ensures excellent stability and healing without residual deformity (Fig. 1).

At 3-month follow-up, a 15-year-old boy with a grade III fracture had modest pain after intense abduction against resistance; this resolved after another 3 months. A 9-year-old patient complained of some discomfort at the site of fracture, but this disappeared within 5 months. There was also one case of superficial cutaneous irritation on the pin tract at 4 weeks (time of wire removal); this patient had no sequelae.

The mean Δ Costant score was 8.43 (range 2–22), and the average Quick DASH score was 0.56 (range 0–1.7). The mean score on the questionnaire for the sports–recreational activity was 1.32 (range 0–6.3). Range of motion tests showed a complete recovery of joint function in follow-up in all cases. For the ten patients with NH grade III, the mean Δ Costant score was 4.2 (range 2–14): 9 were "excellent" and 1 was "good". In the grade IV group, the mean Δ Costant score was 11.06 (range 3–22) with 10 "excellent", 4 "good", and 2 "fair" results versus the contralateral shoulder. In NH grade IV, the closed surgery had 2 "fair", 2 "good", and 6 "excellent" results, while the open surgery resulted in 2 "good" and 4 "excellent" outcomes (Table 3). There was a significant ($p < 0.01$) improvement of 6.87 in the mean Δ Costant score of


(a)
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◀**Fig. 1** P.D. 15-year-old boy. **a**, **b** Antero-posterior and transthoracic radiographs of the left shoulder taken at emergency room showing a displaced Neer type IV fracture of the proximal humerus. **c** Antero-posterior post-operative radiograph of the displaced fracture treated by closed reduction and percutaneous fixation with three Kirschner wires followed by abduction brace. **d** Antero-posterior radiograph 8 days after surgery showing a loss of reduction. **e**, **f** Treatment with open reduction and internal fixation with plate and screws. **g**, **h** Radiographs performed 1 year after surgery showing normal alignment and perfect bone healing. **i**, **j** Clinical view of the patient at 6 months after treatment showing a full range of motion

patients with fractures of degree III compared to those of degree IV.

In grade IV fractures, we observed significant ($p = 0.032$) improvements of 5.17 in the mean Δ Costant score of patients treated with open surgery with respect to patients treated with the mini-invasive surgery. On the other hand, we did not find any difference between the two treatments using the Mann–Whitney's U test ($p = 0.56$). There was no significant correlation between the Δ Costant score and sex $p = 0.95$, between Δ Costant score and age $p = 0.71$, or between Δ Costant score and activity score $p = 0.82$.

Discussion

This retrospective study is focused on the outcomes of surgical treatments of the fractures in the proximal humerus in 26 children. The data show that patients with a grade III fracture have a better outcome than grade IV due to displacement of the fracture. In 16 patients with NH grade IV, we observed better results in those treated with open surgery.

The treatment approach for proximal humeral fractures in children is controlled by the great remodelling potential of the proximal humerus. We adopted the Neer–Horowitz classification system that is based on displacement severity. This is the most indicative system for choosing the proper treatment. Overall non-operative treatment is the first choice for epiphyseal and metaphyseal fractures of the proximal humerus in children. This is mainly in non-displaced fractures where a Desault bandage, a Gilchrist bandage, or a cast are applied followed by radiographic evaluation. In displaced fractures, a closed reduction under general anaesthesia is preferred [2, 6]. Nevertheless, the current trend in the treatment of proximal humerus fractures in children is focused on age and deformity as reported by Bahars [10]. Several studies confirmed that under 10 years the high remodelling potential of the proximal humeral plate allows a non-operative treatment with a proper reduction even in displaced fractures [10–15].

Table 3 NH grade IV: outcomes of Costant score compared to the contralateral shoulder

	Poor	Fair	Good	Excellent
Closed surgery	0	2	2	6
Open surgery	0	0	2	4

According to the literature, most cases of NH grade I and II proximal humerus fractures in children and adolescents are treated non-surgically except for cases of neurological and vascular injuries [15]. Rather, the management of NH grade III and IV fractures is still debated. Two factors must be considered for an appropriate treatment of these fractures: the chronological and skeletal age of the patient and the grade of the displacement. Nevertheless, the literature has no hard guidelines for the amount of displacement or angulation that requires surgical management. We found several differences regarding the tolerable angulation and displacement for NH grade III and IV fractures that are considered as decision criteria of treatment (Table 2).

Pahavlan performed a systematic review and reported that non-operative treatment was the best option in younger children with residual growth. Patients >13 years old with more widely displaced fractures could benefit from anatomical reduction with stabilization. Those 10–13 years should be discussed on a case-by-case basis depending on the extent of displacement and the setting. After an interesting review, Lefèvre defined the need of reduction in three patient subgroups: patients younger than 10 years with translation greater than 100 % and/or angulation greater than 70°; patients aged 10–13 years with translation greater than 50 % and/or angulation greater than 40°; and patients older than 13 years (with an open proximal physis) with translation greater than 30 % and/or angulation greater than 20° [16]. We treated our group according to these indications and also adjusted as a function of patient and family compliance.

Incomplete fracture reduction is mainly caused by interposition of anatomical structures such as the periosteum, biceps tendon, deltoid muscle, comminuted bone. Almost 10 % of severely displaced fractures may have bicep tendon interposition [11]. In these cases, an open reduction must be performed [4]. The precise incidence of the proximal humeral fractures seems to show a peak between 10 and 14 years of age, [17] so there is a clear need for further studies to find a gold standard for these patients. In our study, we did not focus on the patients' age because of the small sample and the inhomogeneous age groups. This precluded statistical analysis.

Complications associated with surgical treatment include migration, superficial infections, and osteomyelitis. These are the principal reasons that surgeons choose to

avoid surgical treatment—they prefer the risk of a misalignment to the risk of osteomyelitis.

The literature suggests that surgical treatment is indicated in the case of unstable and irreducible fractures, in open fractures, and in those cases with associated nervous or vascular injuries [1, 7]. An interesting study by Pandya et al. proposed, with good results, the synthesis of plate and screws in immature (but skeletally mature) adolescents and high demanding athletes [12]. In our series, we had two patients—12- and 16-year-old boys—who showed a failure in the mini-invasive surgery after 2 weeks with a loss of reduction in varus of 15° and 10°, respectively. We made an open reduction and a synthesis with plate and screws. The result was excellent. At 4 months, the subject returned to sports activities. Pandya et al. [4] retrospectively reviewed ten adolescent patients with severe displacement and irreducible fractures who received open reduction with excellent results at 3 years.

Usually, operative management includes multiple options with closed or open reduction: wires, cannulated screws, retrograde elastic stable intramedullary nailing (ESIN), or a plate. All of these surgical techniques have shown excellent results and suggest that the anatomical reduction in severely displaced proximal humerus fractures is always reached. Burgos-Flores et al. reported excellent results in NH grade III and IV proximal humeral epiphyseal fractures treated with closed or open reduction and wire fixation. They noted a more aggressive approach is needed to correct the initial displacement and angulation in teenagers because there is a greater occurrence of residual deformity and limitation of motion in older patients [18]. Wei et al. surgically treated 43 children between 3 and 17 years of age for displaced fractures of NH grade III and IV of the proximal humerus. The mean follow-up was 20.4 months. All children had consolidated fractures and good functional results. All of them returned to their normal physical activities [19].

Fixation with three or four K-wires is often described in the literature. Another technique described with good results is retrograde elastic intramedullary nailing. Hutchinson et al. compared these two techniques and reported that K-wire fixation is less invasive with less common intra-operative complications and a shorter operative time. However, it often results in post-operative immobilization. Moreover, both techniques have good clinical and radiographic outcomes [13]. More studies are necessary to define the specific groups of paediatric candidates suitable for closed or open surgery.

Regarding the assessment scores, we found the Quick DASH score to be more appropriate than a purely radiographic score because QD focuses on the activity level—that is the final goal in the treatment of these lesions. We evaluated the Constant score and compared it to the score of the opposite shoulder to get a better feedback of the actual functionalities for each individual patient. The majority of the children could understand the questions and answer them without help. We observed no correlation between sports activities scores and others scores. This suggests the good ability of children to compensate for anatomical and functional alterations in everyday life.

Conclusions

This study shows excellent results with a minimally invasive treatment with percutaneous k-wires. This is a standard technique that we prefer because it offers shorter surgical time and limits the need to remove the implant. Closed surgery in proximal humeral fractures in children was successful. The excellent outcomes we observed lead us to prefer the mini-invasive surgical approach in NH grade III fractures. In NH grade IV patients, the best results were registered in patients treated with open surgery. According to this, an open approach was first suggested even if open reduction is generally restricted to extremely severe displaced fractures or after a failure of closed reduction.

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Compliance with ethical standards

Conflict of interest Each author certifies that he/she has no commercial associations that might pose a conflict of interest in connection with the submitted article.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

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