MICROSURGICAL RECONSTRUCTION OF BRACHIAL ARTERY INJURIES IN DISPLACED SUPRACONDYLAR FRACTURE HUMERUS IN CHILDREN

HASSAN H. NOAMAN, M.D.*

Between March 2000 and March 2005, 840 children with grade III supracondylar humeral fractures presented for treatment, consecutively at our hospital. One hundred twenty had absent or diminished (detected by Doppler but not palpable) radial pulse on initial examination. Eighty-nine of these 120 children recovered pulse (palpable) after closed reduction and percutaneous pinning of the fracture. The remaining 31 children had persistent absent radial pulse. Twenty-two of the 31 children had median nerve signs. Each of these 31 children was explored. The intraoperative findings were intact median nerve in all cases (neuropraxia), traumatic aneurysm with thrombus formation in 17 cases, complete injury of the brachial artery in 8 cases (loss of continuity), thrombosis in 3 cases, partial tear in 2 cases, and brachial artery entrapment in the fracture site in 1 case. Microsurgical reconstruction of the 31 brachial arteries was done as the following: reversed vein graft for 8 cases, excision and repair in 17 cases, partial repair in 2 cases, thrombectomy in 3 cases, and release of the brachial artery from the fracture site in 1 case. The average follow up was 26 months range (6–60) months. All children had excellent to good functional and cosmetic outcome except one who had Volkman's ischemic contracture, treated later by free functioning gracilis muscle transfer. © 2006 Wiley-Liss, Inc. Microsurgery 26:498–505, 2006.

Supracondylar fractures of the humerus are common and accounts for 60% of all fractures of the elbow in children. More than 95% of all supracondylar fractures are displaced in extension either in a posteromedial or posterolateral direction.[1,2] Rarely anterior displacement of the distal humeral fragment results from flexion forces created by a fall directly on the olecranon.[3,4] Clinical evaluation of a child with a potential supracondylar fracture includes a comprehensive history and physical examination of both the entire upper extremity and the rest of the child to rule out a concomitant injury. The mechanism of injury should be determined. A comprehensive neurovascular examination is necessary to detect nerve damage, vascular impairment or impending compartment syndrome.[2] In the past, the incidence of true permanent sequelae of vascular injuries following displaced supracondylar fractures of the humerus was reported as rare. Because of the increased ability to recognize vascular injury, recent reports have demonstrated higher incidence of vascular injury.[5] Campbell et al.[6] reported that 38% of their cases had evidence of injury to brachial artery. The radial pulse is reported to be absent before reduction in 7–12% of all fractures and up to 19% in displaced fractures. After reduction, the pulse is restored in 80% of the cases.[3,4,7–10] The aim of this study is to report that pulseless forearm with pink or cold hand following satisfactory closed reduction and percutaneous pinning is an indication for exploration of the brachial artery with its concomitant median nerve.

PATIENTS AND METHODS

Thirty-one patients who constitute this article had supracondylar humeral fractures grade III, complicated by brachial artery injury and 22 cases of those had median nerve injury too. Eighteen cases were male and 13 females. The average age was 7 years (range 4–11 years). The affected side was left side in 19 cases and right side in 12 cases. All patients were examined clinically by the author before and after the operative treatment. Clinical examination showed absence of radial pulse in all patients. Open fracture type I occurred in 6 cases, bruising in 4 cases, severe elbow and forearm swelling in 5 cases (Fig. 1), tethering and puckering of the skin in the antecubital region in 2 cases, and palpable subcutaneous medial spike of the proximal humeral fragment in 2 cases. There was concomitant floating elbow (ipsilateral fracture both radius and ulna) in 2 cases. Routine preoperative X-ray AP and lateral views for the elbow and forearm were done to detect the type of fracture, degree of displacement (all cases were type III), associated ipsilateral fracture or intra-articular extension. The degree of displacement reflected the magnitude of complications (Fig. 2). Doppler sonography was used. It was positive in the all cases (i.e., no distal flow in both radial and ulnar arteries with total reduction in the wave at the site and distal to the injury zone (Figs. 3 and 4)).

OPERATIVE TECHNIQUE

All fractures were initially treated by closed reduction and percutaneous kirschner wire fixation under general

Hand and Reconstructive Microsurgical Unit, Orthopaedic Department, Sohag Faculty of Medicine, South Valley University, Sohag, Egypt

*Correspondence to: Hassan H. Noaman, Hand and Reconstructive Microsurgical Unit, Orthopaedic Department, Sohag Faculty of Medicine, South Valley University, Sohag, Egypt. E-mail: hassan_h@mailcity.com

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Figure 1. Photograph showing swelling with ecchymosis of left elbow, in supracondylar fracture humerus with impalpable radial pulse. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Figure 2. Plain X-ray films showing markedly displaced supracondylar fracture humerus with impalpable radial pulse.

anesthesia. Two lateral k-wires from the lateral condyle reaching the medial cortex above the olecranon fossa crossing each other after reduction of the fracture in acute elbow flexion was the standard technique used. The indication for brachial artery exploration was a reduced or absent radial pulse 1 h after satisfactory closed reduction and percutaneous pinning irrespective of the clinical appearance of the hand. The second indication for vascular exploration was absent radial pulse irrespective of the clinical appearance of the hand in cases of open fractures associated with bruising, severe elbow and forearm swelling, tethering or puckering of the skin in the antecubital region, and palpable subcutaneous spikes of the proximal

Figure 3. Normal Doppler wave proximal to the injury zone.

Figure 4. Total reduction of wave distal to injury zone.

humeral fragment. The patient was in supine position under general anesthesia. The upper limb was placed on side arm table. The tourniquet was not used. Foley catheter was used in all cases to check the urine output because of the longer operative time. The entire upper limb was sterilized and draped, the lower limbs were sterilized and draped due to the possibility of the need for a saphenous vein graft, which was used in 6 cases. The approach was anteromedial approach (Fig. 5) extending 5 cm proximal to the elbow crease on the medial side and then extending down to the lateral aspect of the forearm. The venous plexus in the cubital region should be preserved specially the basilic vein, which was used as a graft in 2 cases. The brachial artery is in the next layer just deep to the venous plexus. It is medial to the biceps tendon and lateral to the median nerve covered by lacertus fibrosus at the cubital region. It is very important to look for the artery carefully at the level of the fracture [injury zone]. Exploration of the brachial artery revealed intimal injury with thrombus formation and fusiform swelling (traumatic aneurysm) in 17 cases, complete rup-

Figure 5. Intraoperative photograph showing approach of brachial artery exploration. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

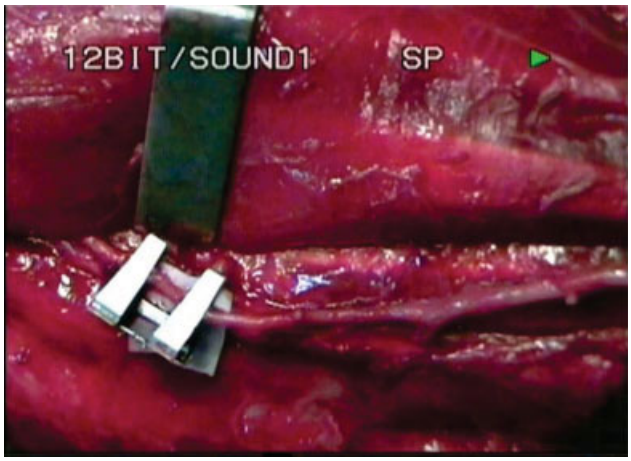

Figure 6. Intraoperative photography showing reversed vein graft. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Table 1. Criteria Degrees (Flynn et al.)

Results	Rating	Cosmetic factor: carrying angle loss (degrees)	Functional factor: motion loss (degrees)
Satisfactory	Excellent	0–5	0–5
	Good	6–10	6–10
	Fair	11–15	11–15
Unsatisfactory	Poor	>15	>15

Figure 7. Preoperative photo of open fracture supracondylar humerus with brachial artery injury. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

ture in 8 cases, thrombosis in 3 cases, partial tear with hole due to avulsion injury of one branch in 2 cases and brachial artery entrapment in the fracture site in 1 case. The median nerve runs parallel and medial to the brachial artery in the cubital region. It was intact in all cases despite the presence of preoperative median nerve signs (pointed index) in 22 cases. The fracture was approached from anterior by open reduction and fixation by K wires in 19 cases presented by open fractures and fractures with manifestations of brachialis muscle tethering. The remainder 12 cases were reduced and fixed percutaneously under image intensifier before exploration of the brachial artery. The thrombosed aneurysm was resected until the vessel wall appeared normal and there was pulsatile flow from the proximal limb. End-to-end anastomoses were performed using interrupted 8-0 or 9-0 nylon sutures in 17 cases. In complete rupture of the brachial artery, it was difficult to do end-to-end anastomoses because of retraction and laceration of both ends. Trimming of both ends was done until the vessel wall appeared normal and there was pulsatile flow from both ends. Reversed saphenous vein graft with average length 5 cm was interposed the arterial defect in 6 cases, and reversed basilic vein graft 4 cm length from the same exposure was interposed the arterial defect in 2 cases (Fig. 6). Thrombectomy by Fugarty catheter in 3 cases, repair of the injured artery in 2 cases and released the brachial artery from the fracture site in 1 case. The skin was closed loosely, no drains or suctions were used. Postoperative above elbow splint in 80–90° flexion without tight bandage was used in all cases. The region above the radial artery was bared to check the pulse regularly every hour. The hand and fingers were checked also regularly for finger motion, skin

Figure 8. Plain X-ray AP and Lat. views of the same patient.

Figure 9. Postoperative plain X-ray AP and Lat. views of the same patient showing good reduction and fixation with 2 lateral k-wires.

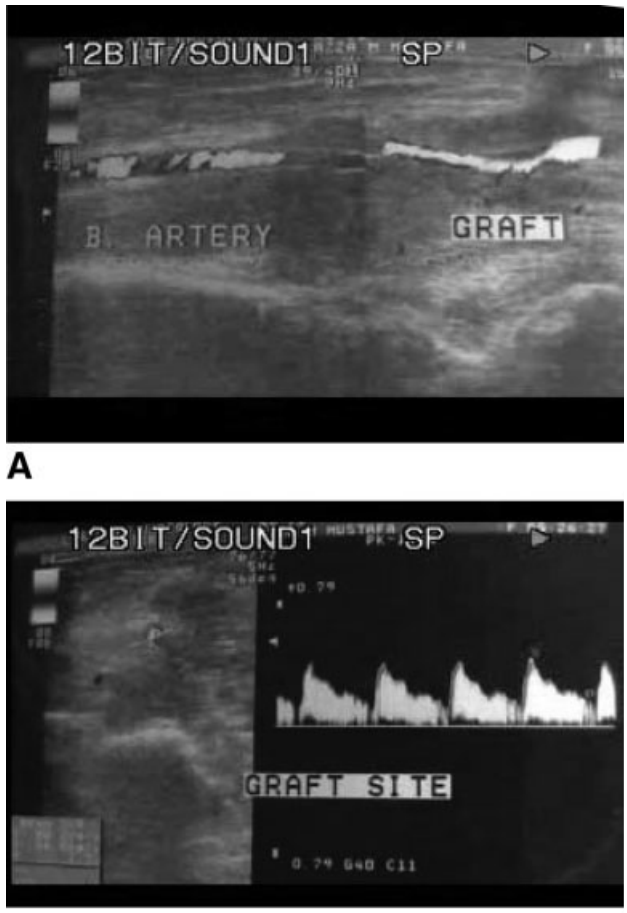

*Figure 10. (**A**), (**B**) Duplex wave at the graft site show patent graft with blood flow inside it.*

color, temperature, capillary filling, and skin turgor. Heparin and other low molecular weight anticoagulant were used in the beginning. Secondary look was carried out in 7 cases due to the presence of active bleeding either from the suturing site or from small branches that were thrombosed and opened postoperatively because of restoration of blood pressure to the normal or the using of heparin and other low molecular weight anticoagulants, so we gave up their use. Patient time in hospital was average 7 days. The k-wires and the splint were removed after 3 weeks. Active and passive elbow movement was started immediately after the removal of the k-wires and the splint. Physiotherapy was done after 4 weeks.

RESULTS

The average follow up was 26 months (range 4–60 months). Check X-ray AP and Lateral views was done for every patient 4 weeks after the treatment and at the final follow up visit. All patients had radiological union. The clinical outcome of all patients at the final follow up visit was evaluated using the functional and cosmetic criteria of Flynn et al.[11] (Table 1). According to the cosmetic factor classification of the 31 patients, all patients met the satisfactory criteria, 22 (71′%) showed excellent results, 7 (23%) had good results, and 2 (6%) showed fair results. According to functional factor, all patients met the satisfactory criteria, with excellent results in 18 cases (60%) (Figs. 7–12), good results in 9 (29%) cases, and

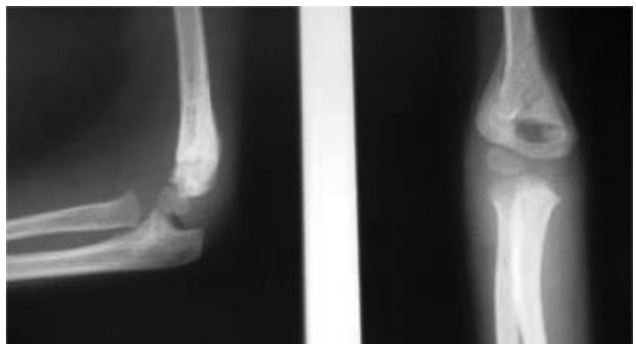

Figure 11. Follow up 6 months, X-ray AP and Lat. views showing good remodeling.

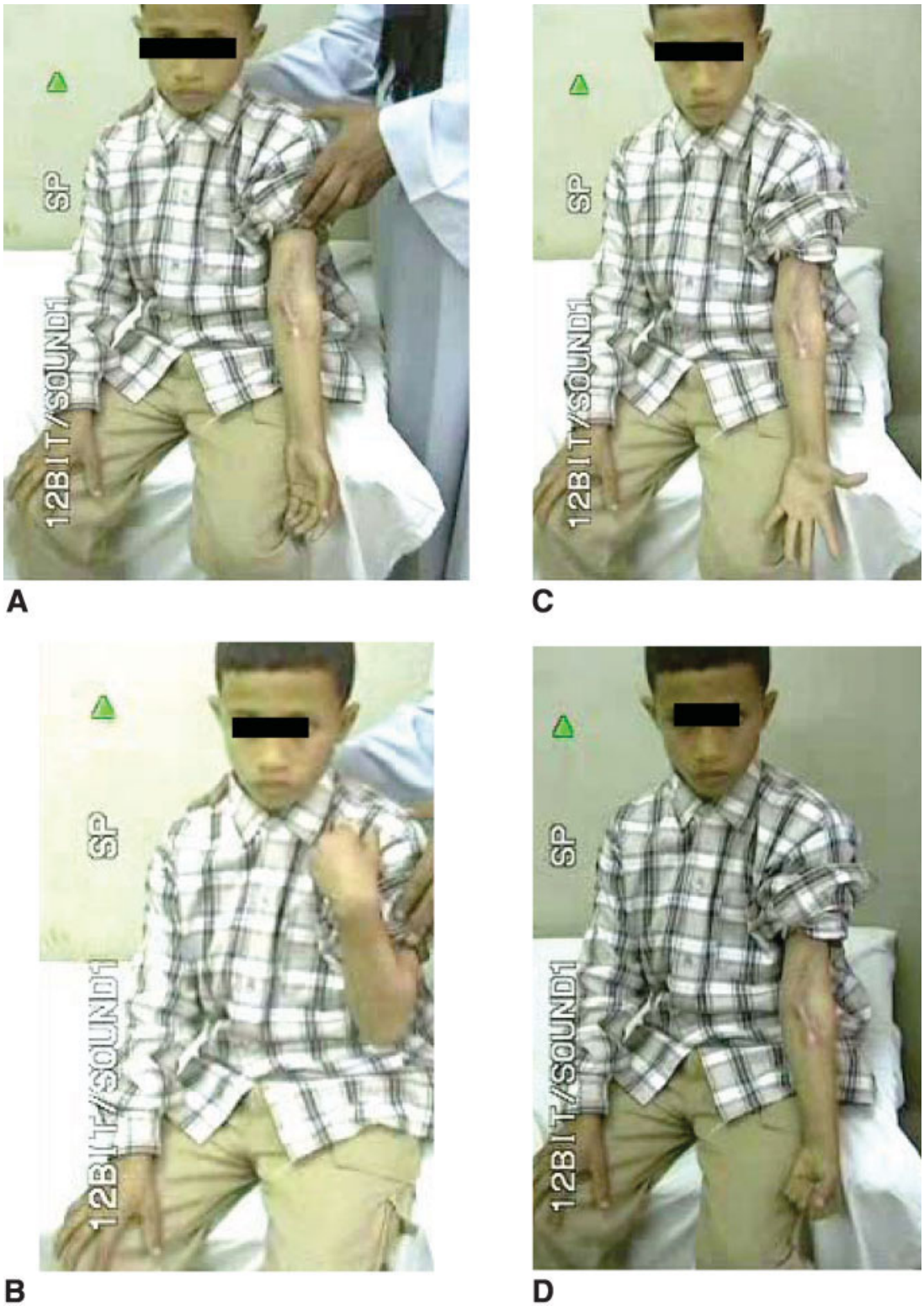

*Figure 12. 48 months follow up of the same patient, (**A**) full elbow extension, (**B**) full elbow flexion, (**C**) full finger extension, and (**D**) full finger flexion. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]*

fair results in 4 (11%) (Table 2). For evaluation of microsurgical treatment of the brachial artery injury, two methods of evaluation were used. The first was clinical methods that included static and dynamic function. The static function includes the presence or absence of peripheral pulse and the quality of circulation to the skin and subcu-

Table 2. Summary of the Results (According to Flynn et al.)

Results	Rating	Cosmetic factor	Functional factor
Satisfactory	Excellent	22 (71%)	18 (60%)
	Good	7 (23%)	9 (29%)
	Fair	2 (6%)	4 (11%)

taneous tissue, as manifested by capillary filling. All the 31 cases had normal static functions, the radial pulse was normal in all cases and was comparable with the uninjured side and the capillary filling also was normal in all the cases. The dynamic function was determined by the clinical evaluation of muscle activity, which indirectly measures the adequacy of circulation to these structures. All the patients had normal dynamic functions except one who developed Volkmann's ischemic contracture and was treated by excision of the nonfunctioning fibrous tissue and replaced by free vascularized gracilis muscle transfer. The second method for evaluation of the results following percutaneous pinning and brachial artery management was Doppler sonography. The distal flow in both radial and ulnar arteries was measured and compared with that of the contralateral radial and ulnar arteries. The appearance of the graft and the site of repair was carried out. There was normal distal blood flow in both radial and ulnar arteries in all cases. There was neither stenosis at the site of repair nor at both ends of the grafts.

DISCUSSION

Supracondylar fracture of the humerus in children is a common childhood injury accounting for 3–7% of all fractures[12] and the majority (55–80%) of all elbow fractures in children.[13,14] The commonest type is the extension fracture in which the condylar complex shifts posteromedially or posterolaterally after a fall on the outstretched arm, but in 2% the condylar complex shifts anterolaterally: the flexion type fracture.[4,9] More than 95% of these fractures are displaced in extension, which may lead to a variety of neurological and vascular complications.[1] In this series all the supracondylar fractures were extension type and the mechanism of injury was falling on the outstretched arm. Louahem et al.[15] reported that 29 patients (14%) out of 210 children suffering from severely displaced supracondylar fracture humerus had vascular complications. Skaggs and Pershad[1,16] reported that the incidence of vascular injury of displaced supracondylar fractures has ranged from 3 to 12% of patients. Campbell et al.[6] reported that 38% of their cases had evidence of injury to the brachial artery. Houshian et al.[17] reported that five children out of 35 with displaced supracondylar fracture humerus type III had brachial artery injuries. The incidence of vascular injury in this series (included 840 patients) was 15%. The spectrum of vascular injuries occurs with both primary and secondary effects of the fracture. The primary effects are the result of direct injury to the brachial artery by the fracture fragments. This degree of injury may vary from simple compression of the vessel by the fracture fragments to a complete rupture. Even if the injured artery remains in continuity, obstruction of the involved segment can be caused by intimal tear. The secondary effects depend on the degree and type of vascular insufficiency that develops distal to the fractures site. Ottolenghi[5] divided the secondary effects of vascular insufficiency into four stages of severity: massive gangrene, partial muscle necrosis and peripheral gangrene, ischemic fibrosis (Volkmann's contracture), and deficient circulation not apparent at rest but present with activity (intermittent claudication). In this study the spectrum of injuries was traumatic aneurysm with thrombus formation in 17 cases, complete rupture of the brachial artery in 8 cases, thrombosis in 3 cases, partial tear in 2 cases, and brachial artery entrapment in the fracture site in 1 case. Only one case had secondary effect with development of Volkmann's ischemic contracture. The management of a child with an absent radial pulse following closed reduction remains controversial.[1,18] Many surgeons are reluctant to explore a supracondylar fracture with neurovascular deficit because the limb is usually not threatened,[6,17,19] while others recommend brachial artery exploration in cases of white pale hand,[20] but it is clear that a significant arterial injury may exist without a detectable change in distal pulse or evidence of ischemia.[21] In this series the main indication for exploration of the brachial artery was absent radial pulse either after closed reduction and percutaneous pinning or in cases with high risk of brachial artery injury as in open fractures, brachialis muscle tethering, and sever elbow swelling. In this series 120 cases had impalpable radial pulse following displaced supracondylar fractures, 89 cases regained palpable radial pulse after closed reduction and percutaneous pinning, and 31 cases had brachial artery injury on exploration (i.e. no negative exploration). This means spasm, kinking or impaled brachial artery should be improved by reduction and fixation. In the past, invasive techniques such as arteriography have been used[20,22,23] but many now believe that arteriography often only confuses the issue. It can also delay the usual urgent need to relieve the vascular compromise by surgical exploration. Noninvasive techniques have become more popular in recent years. The most common is the vascular Doppler. Shaw et al.[23] believed that the absence of a Doppler reading on the radial artery was in itself an indication for immediate surgical exploration of the artery. However the audible pattern still does not adequately quantify marginal degrees of circulatory insufficiency. In an effort to make the Doppler a more accurate instrument for measuring the volume of

blood flow to the extremity, Vasili[24] has quantified the wave form on a spectral analyzer. Visual presentation of the wave form can be compared with that of the uninjured extremity to give a better indication of the quality of blood flow to the extremity. In this study we used vascular Doppler preoperatively and postoperatively measuring both the volume of blood flow to the extremity and visual presentation of the wave form compared with the uninjured extremity. It has big value in doubtful cases, specially cases with absent radial pulse and pink hand. Many authors[1,25–27] recommend surgical exploration of a suspected brachial artery injury in contrast to conservative approach recommended by others.[6,17–19] A further advantage of surgical exploration is that the fracture can be reduced under direct vision, thereby avoiding further damage to the neurovascular bundle.[1,26] The goals of revascularization of the upper extremity are prevention of digit or limb loss, and preservation of long term function.[28] One of the disadvantages of exploration is the introduction of a scar, although most of the incision is hidden by the upper arm and is cosmetically acceptable.[1] The conversion of a closed fracture to an open injury may constitute an increased risk of infection but in this series there were no wound infections and no bony nonunions. The temporal relation between injury and treatment is especially important. Ottolenghi[29] found that the incidence of Volkmann's ischemic contracture was zero in supracondylar fractures with vascular compromise that were treated by exploration of the artery within the first 12 h. The incidence rose slightly if the interval was from 12 to 24 h. Almost all of the cases of Volkmann's in his series occurred in those explored later than 24 h after injury. In this study most cases were explored before the 12 h. The only patient who developed Volkmann's ischemic contracture in this study was due to bleeding from the surrounding tissue and lack of follow up postoperatively. The clinical outcome of all patients at the final follow up visit showed that, all patients had normal radial pulse, pink warm hand and normal dynamic functions of the hand except one who developed Volkmann's ischemic contracture and treated by free vascularized gracilis muscle transfer. The cosmetic and functional outcome of the elbow was assessed using Flynn et al.'s criteria.[11] According to the cosmetic factor classification of the 31 patients, all patients met the satisfactory criteria, 22 (71′%) showed excellent results, 7 (23%) had good results, and 2 (6%) showed fair results. According to functional criteria, all patients met the satisfactory criteria, with excellent results in 18 cases (60%), good results in 9 (29%) cases, and fair results in 4 (11%) (Table 2). The results of this study is lower than that of Shim and Lee.[30] They used the Flynn et al. criteria[11] for analysis of 63 patients but without neurovascular complications. Their results were 47 (74.6%) with excellent results, 15 (23.8%) good results and none showed fair results. One patient (1.6%) was classified as having an unsatisfactory outcome because of the varus deformity. According to the functional outcome all their patients met the satisfactory criteria with excellent results in 58 (92.1%) and good results in 5 (7.9%) of the patients. Of 830 cases of supracondylar fractures reviewed, Ottolenghi[29] reported 39 cases treated for vascular injury or compromise, for an incidence of almost 5%. Eight of these cases, however developed the full blown picture of Volkmann's ischemic contracture, for an incidence of $<1\%$. The results of this study are better than those of Ottolenghi.[29] In this study 840 cases of supracondylar fractures reviewed; we reported 120 cases treated for vascular injury or compromise for an incidence of 15%. Only one patient of those developed Volkmann's ischemic contracture for an incidence of 0.1%.

CONCLUSIONS

Indications of brachial artery exploration with supracondylar fracture humerus with impalpable radial pulse were:

1. Pulseless forearm with pink or cold hand
2. Absent radial pulse one hour after satisfactory closed reduction and percutaneous pinning
3. Absent radial pulse with open supracondylar fracture or signs of brachialis muscle tethering e.g. bruising or severe elbow swelling, puckering of the skin in the antecubital region and a palpable subcutaneous medial spike of the proximal humeral fragment.

The usage of heparin and low molecular weight anticoagulant after the treatment of brachial artery injury increases the incidence of secondary look and leads to Volkmann's ischemic contracture due to bleeding from the suturing site and the surrounding.

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