A review of K-wire related complications in the emergency management of paediatric upper extremity trauma

H SHARMA¹, GR TAYLOR², NMP CLARKE²

¹Department of Trauma and Orthopaedics, Royal Hospital for Sick Children, Glasgow, UK

²Department of Trauma and Orthopaedics, Southampton General Hospital, Southampton, UK

ABSTRACT

INTRODUCTION Kirschner wires (K-wires) are immensely versatile in fracture fixation in the paediatric population. Complications associated with the K-wiring procedure vary from minor to a life-threatening. The aim of this study was to analyse the outcome of fracture fixation using K-wires in all types of upper-extremity fractures in children in order to assess the incidence and type of complication critically.

PATIENTS AND METHODS Between September 1999 and September 2001, we retrospectively reviewed a consecutive series of 105 fractures in 103 paediatric trauma cases (below 12 years) treated with K-wires in a university teaching hospital. The case notes and radiographs were reviewed by an independent single assessor. All paediatric, acute, upper-extremity, displaced and unstable fractures were included. All elective procedures using K-wires were excluded.

RESULTS We observed an overall 32.3% complication rate associated with the K-wiring procedure affecting 34 pins (24 patients). Wound-related complications included over-granulation in 13 cases, pin tract infection in 6 cases and hypersensitive scar in 1 case. Neurapraxia was found in 3 patients and axonotmesis in 1 patient. Wire loosening at the time of removal in 14 cases and retrograde wire migration in 4 cases were observed. There were 2 cases of penetrating tendonitis and 1 case of osteomyelitis. There was a higher complication rate in terms of wire loosening and pin tract infection when the K-wires: (i) were left outside the skin compared with those placed under the skin; (ii) stayed longer in the patients; and (iii) did not traverse both cortices. There were more complications in complex operations performed by senior surgeons ($P = 0.056$). The duration of K-wire stay, associated co-morbidity and anatomical location were statistically insignificant.

CONCLUSIONS Complications are part of operative procedures; an important point to consider is what causes them in order to take preventative measures. We recommend that the risks and complications should be explained to parents during the consenting process to allay their anxiety, irrespective of the fact that most complications are minor and of short duration.

KEYWORDS

K-wires – Paediatric fractures – Fixation – Complications

CORRESPONDENCE TO

Himanshu Sharma, 44 Abercorn Road, Newton Mearns, Glasgow G77 6NA, UK
E: hksharma1@aol.com

Kirschner wires (K-wires) are immensely versatile in fracture fixation in the paediatric population. Complications associated with the K-wiring procedure vary from minor to life-threatening. There are several reports in the literature describing fatal complication following distant migration of a K-wire to vital structures such as the heart, thoracic big vessels and lungs.^{1–8} Minor complications could be important factors in enhancing parental anxiety and prolonging patients' recovery; however, they are extremely under-reported.

Previously published studies have emphasised the complications specific to a particular fracture in children rather

than implant specific.^{9–21} Stahl and Schwartz²² reported 15.2%, Botte *et al.*²³ found 18%, and Stern and Fulton²⁴ reported 42% complication rates with K-wiring procedure, but these were confined to the hand and wrist region and related to adult patients. There are no studies specifically examining the complication rate associated with use of K-wires in fracture fixation in children regardless of their specific anatomical location. The aim of this study was to analyse the outcome of fracture fixation using Kirschner wire in all types of fractures of the upper extremity in children in order to assess the incidence and type of complication critically.

Patients and Methods

Between September 1999 and September 2001, we retrospectively reviewed a consecutive series of 105 fractures in 103 paediatric trauma cases (below 12 years of age) treated with K-wires in a university teaching hospital. The case notes and radiographs were reviewed by an independent single assessor. All paediatric, acute, upper extremity, displaced and unstable fractures were included, which were treated with K-wires. All lower extremity fractures and all elective procedures using K-wires were excluded. The variables studied were gender, side, mechanism of injury, indication for K-wiring with regard to fracture distribution, timing of procedure, mode of K-wiring, wound-related, neurological and metal-related complications with K-wire fixation, correlation of duration of K-wire stay to the amount and type of complications. We analysed the complications according to the sources (*i.e.* patient, surgeon, procedure and severity of injury) and according to the type of complication. There was a two-tier registrar rota in use during this study period, in which specialist registrars (years 1–6) performed the majority of procedures. In total, there were 53 junior grade surgeons (52 junior specialist registrars and 1 senior house officer) and 52 senior grade surgeons (44 senior specialist registrars, 4 staff grade surgeons, 4 consultants). All senior house officers and specialist registrars in years 1–3 of their training were included in the junior-grade surgeon category. All consultants, associate specialists, staff-grade surgeons and specialist registrars in years 4–6 of their training were included in the senior-grade surgeon category. We are unable to provide information about supervision in those cases where consultants were supervising unscrubbed in theatre or readily available in the hospital as their names were not documented in the operation notes.

Smooth, stainless-steel pins measuring 0.9–1.6 mm in diameter were inserted with a power drill. One to three K-wires were used in order to stabilise any individual fracture of the upper extremity in children. In total, 206 pins were used. Pins were left protruding through the skin with exposed end acutely bent in 70 (66.6%) fractures or were cut-off just beneath the skin in 35 fracture fixations (33.3%). Pins were protected with sterile cast padding. The total life-span of the K-wire (the period between time of insertion and time of removal) varied from 3–6 weeks with a small peak at 4.5 weeks (Fig. 1). Of the K-wires, 80% were removed under general anaesthesia, and the remainder in the out-patient clinic without anaesthesia.

Pin-tract infection was diagnosed when there was documentation of seropurulent discharge/erythema around the pin-site, with or without bacteriological evidence of infection. These pin-site infections either required therapeutic antibiotics or revision procedure as wound debridement. Overgranulation and hypersensitive scars were documented in the case notes. Metal migration was defined as more than 2 mm antegrade or retrograde motion of the wire, as reported in the radiologist's report: this could be local or distant (complete wire migration, revealed as missing wire from the site of insertion). Metal loosening was assessed in this retrospective study by documentation of ease of removal. We would like to stress that fixation remained adequate in all these patients; therefore, wire loosening was not considered as a complication. Loss of reduction was defined as more than 30% loss of reduction and alignment at 1–2 weeks from the injury, which was considered as unacceptable to leave alone by the treating paediatric orthopaedic surgeon. All neurological complications were considered iatrogenic which were not detected or mentioned as normal pre-operatively. Obtaining full recovery within 3 months was labelled as neurapraxia and longer than 3 months as axonotmesis.

The study group included 64 boys and 39 girls. The mechanism of injury is summarised in Table 1. There was no predilection for laterality. Three-quarters of the patients had a K-wiring procedure performed on the day of their admission; 17% underwent manipulation and K-wiring after detection of the loss of reduction at 1-week clinic follow-up. A closed percutaneous technique was used in 64 (60.9%) cases, while 27 (25.7%) cases were treated by open and 14 (13.3%) by combined approaches. The combined approach was predominantly used for fixation of displaced supracondylar distal humeral fractures with open medial and closed lateral approach. All the lateral condylar fractures (isolated or complex) had open reduction and K-wire fixation. The fractures around the wrist (47.6%) and around the elbow (45.7%) comprised the major bulk. In descending order, supracondylar fracture of the distal humerus, distal radius, distal radius–ulna and lateral condyle fracture of the

Table 1 Mechanism of injury in 105 paediatric fractures treated with K-wires

Fall off chair/bed/height < 4 feet	22
Fall while running	19
Fall off climbing frame	11
Fall off roller blade	9
Fall at home	8
Fall from swing	7
Fall off push-bike	5
Fall off horse/mule	5
Fall off skate board	4
Fall off slide	4
Fall downstairs	4
Punching	2
Fall during ice skating	2
Non-accidental injury	2
Fall on ice	1

Table 2 Indication of K-wiring with regard to fracture

Distal radial fracture	26
Distal radius-ulna fracture	22
Mid-shaft radius-ulna fracture	2
Trans/inter-condylar fracture elbow	3
Supracondylar fracture distal humerus	
Gartland type IIA	5
Gartland type IIB	4
Gartland type III	27
Lateral condyle fracture	
Milch type I	4
Milch type II	2
Lateral condyle fracture associated with olecranon fracture	2
Lateral condyle fracture associated with posterior dislocation of elbow	1
Metacarpal fracture	4
Hand phalangeal fracture	3

elbow were the four most common fractures fixed during the emergency period using K-wires (Table 2).

Subgroup analysis was carried out along with statistical analysis in the form of following four categories: (i) procedures performed by junior grade surgeons versus senior grade surgeons; (ii) duration of K-wire stay < 4 weeks versus > 4 weeks; (iii) presence of co-morbidity versus healthy children; and (iv) anatomical location of K-wires around the elbow versus around the wrist. Co-morbidity in 8 patients included Legg-Calve-Perthes disease, hemimelia fibular hypoplasia, truncus arteriosus, pulmonary atresia, Hirschsprung's disease, transposition of great vessels (one each) and osteogenesis imperfecta (two cases).

Statistical analysis

Statistical analysis was performed using the Chi-square test and Fisher exact test (Statistica for Windows 5.1). A *P*-value for the level of significance < 0.05 was considered as statistically significant.

Results

This study comprised 105 fractures in 103 paediatric patients treated with K-wires. We observed an overall 32.3% complication rate with K-wiring procedure (Table 3). The mean follow-up was 10.2 months (range, 2–24 months). Wound-related complications included over-granulation in 13 cases, pin-tract infection in 6 cases and hypersensitive scar in one case. No chronic or deep soft tissue infections were observed. Neurapraxia affecting superficial branch of

Table 3 Complications related to K-wires in a variety of paediatric trauma cases

Wound-related complications	
Over-granulation	13
Soft-tissue infection	6
Hypersensitive scar	1
Neurological complications	
Neurapraxia	3
Axonotmesis	1
Metal-related complications	
Metal migration	4
Loss of position	
Revision K-wiring	2
Re-manipulation under anaesthesia and plaster	1
Miscellaneous complications	
Tendonitis	2
Osteomyelitis	1

the radial nerve (two patients) and ulnar nerve (one patient) were detected postoperatively. One case had axonotmesis involving the anterior interosseous nerve. All neurological complications were resolved over a period of time. Fourteen cases had wire loosening indicated by the ease of wire removal. Four patients showed retrograde wire migration

Table 4 Statistical analysis of complication rates in K-wiring for paediatric upper limb trauma with regard to surgeon grade, duration of implant stay, associated co-morbidity and anatomical location

	Senior grade surgeon	Junior grade surgeon	P-value
Uncomplicated	36	45	0.056
Complicated	16*	8	
Total	52	53	

	Duration for removal of K-wires		P-value
	(< 4 weeks)	(> 4 weeks)	
Uncomplicated	27	54	0.7
Complicated	7	17	
Total	34	71	

	Without co-morbidity	With co-morbidity	P-value
Uncomplicated	74	7	0.41
Complicated	23	1	
Total	97	8	

	Around elbow	Around wrist	P-value
Uncomplicated	36	39	0.7
Complicated	12	11	
Total	48	50	

*12 of 16 were severe and complex trauma.

indicated by presence of K-wires in the cast or longer protruding part of the K-wire than the initial protruding portion. The majority of patients with pin loosening were associated with wound-related complications. There were no fatal complications resulting from antegrade wire migration to the vital structures. Two patients had undergone revision K-wiring, while one had undergone removal of K-wires, re-manipulation and plaster application. There were two cases of impalement tendonitis affecting extensor carpi ulnaris and extensor pollicis longus tendons. These were spontaneously resolved. One case of osteomyelitis was noted affecting the mid-diaphyseal part of the radius. It was successfully treated conservatively with appropriate antibiotic therapy and close observation. This patient had a complete recovery.

Out of 24 patients with complications, 23 had no co-morbidity, 12 were severe, 17 had removal of pins > 4 weeks and 16 were operated by senior grade surgeon (Table 4). There were 16 complications in procedures performed by senior grade surgeons and 8 in procedures done by junior grade surgeons. However, the difference between procedures performed by senior grade surgeons and junior grade surgeons was statistically insignificant ($P = 0.056$). We would like to

stress here that 12 of 16 complications occurred in severe and complex trauma operated by senior surgeons. The difference was statistically insignificant for complications around the elbow operations versus around the wrist ($P = 0.7$). There was no statistical difference between patients with significant co-morbidity versus healthy children ($P = 0.41$). There were only 7 complications in patients where K-wires were removed within 4 weeks compared with 17 in those after 4 weeks, but the difference was not statistically significant ($P = 0.7$).

Discussion

Fritz Steinmann (1907) used a single-ended pin and Martin Kirschner (1909) used a double ended pin for skeletal traction.^{7,22,29} Smooth Kirschner pin fixation is a common and very versatile method of internal fixation of paediatric fractures – but are they inherently benign? This study is an overview of the complications of the K-wiring procedure used for the emergency management of a variety of upper extremity paediatric traumas irrespective of their specific anatomical location. There were no fatal complications in this series. Overall, 32.3% of patients had minor to major complications and all were eventually resolved in due course without any residual sequelae.

Our study is the first report documenting the K-wire associated complication rate in paediatric trauma irrespective of specific anatomical location. Complication rates in few of the previously published relevant studies such as Stahl and Schwartz (15.2%),²² Botte *et al.* (18%)²⁵ and Stern and Fulton (42%)²⁴ are all related to adult patients and studying hand and wrist region. Leet *et al.*²⁰ observed 30 patients (18.98%) with unsatisfactory results in a review of 158 type 3 supracondylar humerus fractures. Leet *et al.*²¹ reported higher complication rates (33%) in a retrospective study of 21 medial condylar fractures. The authors recommended adequate stabilisation of the fracture using K-wire and immobilisation until there is radiographic evidence of healing. Starker and Eaton²⁵ observed a low complication rate for K-wire pins placed in the emergency room with no patient developing osteomyelitis or pyarthrosis or deep pin track sepsis. We believe that K-wiring in the accident and emergency room would not be a practically feasible option for the paediatric patients.

Pin-related complications

WOUND-RELATED COMPLICATIONS

This study revealed significant wound problems in the form of over-granulation in 13 cases, pin-tract infection in 6 cases and hypersensitive scar in one case. No chronic or deep soft-tissue infections were observed. Cheng *et al.*¹⁷ analysed 403 cases of supracondylar fracture of the humerus in children. They found two cases of superficial pin tract

infection. Botte *et al.*²⁵ observed infections in 10 patients (7%) and pin loosening without infection in 6 (4%) out of 137 patients. Leet *et al.*²⁰ presented a retrospective review of 158 type 3 supracondylar humerus fractures. They found no correlation between an increase in time to surgical intervention and longer operative time or need to open the fracture site, nor was there an indication that the delay to surgical treatment resulted in a longer hospital stay or an increase in unsatisfactory results.

Green²⁶ described the factors associated with pin-tract infection stressing motion at the pin–bone interface, necrotic bone or soft tissue around the pin and soft tissue tension where the pin exits the skin. Pin-tract infections were treated with the removal of the pin and sequential dressings. No deep soft-tissue infection occurred. All patients had full recovery at 3 months' follow-up.

METAL-RELATED COMPLICATIONS

Distant migration such as migration of K-wire into right ventricle, intrathoracic migration into main pulmonary trunk, cardiac arrhythmia, Brown-Sequard syndrome, pericardial tamponade, haemoptysis due to migration of a fractured K-wire to bronchial tree, false aneurysm of brachial artery, intracranial and intra-abdominal migration of K-wire from the field of plastic surgery, *etc.* are intimidating reports with a near fatal or fatal outcome.^{1–8,27–29}

Lyons and Rockwood⁷ mentioned 49 cases K-wire migration (including 17 to major vascular structures and 8 deaths). The mechanism of this migration was loosening of the K-wire secondary to the movement of shoulder girdle over the pin ends. The movement along tissue planes was felt to be due to muscle action and the effects of gravity in various studies.^{7,8}

Due to their inherent smooth nature, K-wires are prone to migrate. To prevent this, pins were bent and left outside the skin in the majority of the patients in the current series. We found 14 cases with wire loosening indicated by the ease of wire removal. We would like to stress here that the fixation remained adequate in all these patients; therefore, wire loosening was not considered as a complication by the authors. Four patients showed retrograde wire migration indicated by the presence of K-wires in the cast or longer protruding part of the K-wire. Ten of these patients had wound-related complications in the form of over-granulation and pin-tract infection. Pin loosening without infection occurred in four cases. There was no fatal or near fatal complication resulting from antegrade wire migration to the vital structures. Complications related to technical difficulty were found in three cases, while four cases had unfavourable outcome due to poor patient compliance.

NEUROLOGICAL COMPLICATIONS

Gosens and Bongers³⁰ recorded a 16.5% rate of neurological impairment out of 200 patients. All recovered without

sequelae in this series except for one case with persistent radial nerve palsy, which recovered after a sural nerve interposition graft. Cheng *et al.*¹⁷ reported only one case of ulnar nerve palsy associated with the pinning; however, 10.5% had an initial nerve palsy related to the injury. Rasool³¹ studied 6 cases of ulnar nerve injury after K-wire fixation of supracondylar humerus fractures in children. Full nerve recovery occurred in three cases, partial in two and no recovery in one. The author recommended an early exploration rather than simple pin removal.³¹ Ikram³² mentioned four children, who developed ulnar nerve palsy following percutaneous fixation of supracondylar fracture of the humerus by K-wires. The author observed that the recovery in three patients took an average of 6 weeks after removal of the wires and only after exploration and adhesiolysis of the ulnar nerve.³²

We agree with the statement by Royce *et al.*³³ that injuries to the nerve due to pinning techniques are more common than indicated in the literature. The rate of iatrogenic injury has been reported to be 2–3%. We found 4 cases of iatrogenic nerve injuries (3.8%); neurapraxia affecting superficial branch of the radial nerve (two patients) and ulnar nerve (one case) were observed postoperatively. One case had axonotmesis involving anterior interosseous nerve. All patients regained full neurological functions. We would like to stress here that proper assessment and documentation of neurovascular status of the limb, both before and after the procedure, is paramount.

TENDONITIS AND OSTEOMYELITIS

Flexor tendon impalement and rupture has been described in the adult trauma cases around the wrist. Botte *et al.*²⁵ reported two patients in whom flexor digitorum profundus tendon was implicated, Fambrough and Green³⁴ documented a flexor tendon rupture caused by a protruding screw. There were two cases of impalement tendonitis affecting extensor carpi ulnaris tendon and extensor pollicis longus tendon in our study. Tendon functions were fully recovered soon after the removal of the pins.

In previous studies, osteomyelitis developed in 1% of the patients with pin tract infections.²³ One case of osteomyelitis was noticed affecting the mid-diaphyseal portion of the radius in this study. It was successfully treated conservatively with appropriate antibiotic therapy and close observation. This patient had a complete recovery.

Fracture-fixation complications

McLauchlan *et al.*¹² studied 68 children in a prospective, randomised, controlled trial who had a completely displaced metaphyseal fracture of the distal radius treated either by manipulation under anaesthesia and application of an above-elbow cast alone or by the additional insertion of a percutaneous K-wire. Maintenance of reduction was significantly better in the

K-wire group and fewer follow-up radiographs were required. Seven of 33 patients in the manipulation-under-anaesthesia group had to undergo a second procedure because of an unacceptable position compared with none of the 35 in the K-wire group.¹² Similarly, Gibbons *et al.*³⁵ allocated 23 patients randomly to one of two treatment groups – manipulation and cast alone, or manipulation and percutaneous Kirschner wiring with cast. These two groups were followed up clinically and radiographically until union occurred. Those fractures treated by percutaneous wiring had no significant complications, and all had a satisfactory result. The fractures treated by manipulation and casting alone required further manipulation in 10 cases.³⁵ Botte *et al.*²⁵ found loss of reduction in six (4%) out of 137 patients.

In this series, 17% had undergone manipulation and K-wiring after detection of the loss of reduction at 1-week clinic follow-up. Ten patients had loss of initial position at 1-week follow up after K-wiring. In seven out of ten cases, the position was accepted for natural remodelling due to minimal displacement (< 30%). All these seven fractures united well without any sequelae. Two out of ten cases with loss of initial reduction had undergone revision K-wiring for Gartland type III supracondylar fracture distal humerus and displaced fracture distal radius-ulna, while the remaining one case underwent removal of K-wires, re-manipulation and plaster application for re-displaced and severely blistered type III supracondylar fracture distal humerus.

The literature reveals existing controversies regarding the issue of timing of implant removal which ranges from 3–8 weeks.^{10,18,19,20} In this regard, our findings are consistent with a study conducted by Thomas *et al.*¹⁰ in which the authors concluded a period of 3 weeks of smooth K-wire fixation and elbow immobilisation sufficient to achieve healing in most displaced fractures of the lateral humeral condyle treated by open reduction. Furthermore, Pirone *et al.*¹⁸ advocated percutaneous K-wire fixation as the method of choice for displaced extension-type supracondylar fracture of the humerus for a period of 3 weeks to achieve highest percentages of excellent results. On the contrary, Cardona *et al.*¹⁹ and Leet *et al.*²⁰ emphasised that implants should not be removed until healing can be demonstrated radiographically. This time averaged 6 or more weeks in most of the patients in displaced fractures of the lateral humeral condyle.^{19,20}

It is shown in this study that there was a clinical correlation between duration of K-wire stay and amount of complications. We observed that the longer the K-wire stayed in the patients, the higher were wound- and wire-related problems. There was a higher incidence of pin-tract infection, over-granulation, pin loosening and pin migration in patients where K-wires were removed between 4–7 weeks. We believe that prolonged K-wire stay causes over-granulation at the pin-entry site, which favours soft-tissue maceration and infection. Pin loosening and some degree of retrograde pin migration can then result from an

established soft-tissue infection. There was an increase in pin-tract infections and loosening in patients where the K-wire did not traverse both cortices (7/34 pins). There was a higher complication rate in terms of wire loosening and pin-tract infection when pins were left outside the skin compared with those placed under the skin. Botte *et al.*²⁵ found that in all pins left for more than 6.5 weeks, 22% developed complications.

One to three K-wires were used in order to stabilise any individual upper extremity fracture. In total, 206 pins were used, of which 34 pins had complications in 24 patients. Ten patients with hyper-granulation also had pin-tract infection in 6, and retrograde wire migration in 4, patients. Therefore, we conclude that there is a 16.5% chance of a complication with each pin placed (33% for 2 pins); therefore, use only as many pins as necessary and no more. There were three main sizes of pin used in the majority of the patients; however, it could not be determined whether the larger or smaller diameter pins lead to more complications. This was due to lack of documentation of K-wire size in all the patients' operation notes and a disproportionately higher number of pin usage of larger size.

Almost all the pins (Fig. 1) were left in place longer than 3 weeks. This can be justified by the fact that most supracondylar fractures take 3–4 weeks to heal while most forearm and lateral condyle fractures take 4–6 weeks. We conclude that supracondylar pins can be left in place outside the skin safely for 3–4 weeks, while forearm and lateral condyle pins can safely be placed and left under the skin for 4–6 weeks.

Being a retrospective study, the main limitation of the study was inadequate, or lack of documentation of some of the findings. The reliability of the assessor could not be assessed, as there was a wide range of experience in the surgeons reviewing these patients in the clinic from senior house officer to consultant. Nevertheless, this study provides meaningful data on factors influencing complications with K-wiring in emergency paediatric trauma management.

Very little evidence is available directed specifically towards the possible problems and pitfalls associated with the use of K-wire fixation in the paediatric population. K-wiring fixation procedure is the most available and forgiving technique for the fixation of the majority of the fractures in the children and adults. It should be emphasised that, in most of the patients studied, serious permanent sequelae did not occur. In view of a higher complication rate, we recommend that minor complications should be explained during the consenting process in order to allay parental anxiety. Technical failures were few in this series which can further be reduced to a minimum with more supervised operative procedures. Pre-operative planning, intra-operative proper pin placement and postoperative patient compliance (including patient and parental education not to engage in inappropriate activity prematurely) could reduce the complication rate. As revealed in this study, complications in K-wiring procedure are multifactorial. There were more complications in complex cases (even though performed

by senior grade surgeons) and those with prolonged stay (> 4 weeks). Further studies are needed to compare the complication rates in the paediatric versus adult population.

Conclusions

K-wires are versatile but are not inherently benign. Complications are part of operative procedures and it is important to determine what causes them in order to take preventative measures. Explaining potential minor complications would not only allay anxiety, but may also be appropriate from a medicolegal point of view. We recommend explanation of all the minor risks and complications of K-wiring procedures to parents during consenting. This study confirmed that complications in K-wiring procedure are multifactorial. There were more complications in complex cases (even though operated on by senior grade surgeons) and those with prolonged stay (> 4 weeks).

References

1. Daus GP, Drez Jr D, Newton Jr BB, Kober R. Migration of a Kirschner wire from the sternum to the right ventricle. A case report. *Am J Sports Med* 1993; **21**: 321-2.
2. Haapaniemi TA, Hermansson US. Cardiac arrhythmia caused by a Kirschner wire inside the heart. An unusual complication of finger osteosynthesis. *J Hand Surg Br* 1997; **22**: 402-4.
3. Seipel RC, Schmeling GJ, Daley RA. Migration of a K-wire from the distal radius to the heart. *Am J Orthop* 2001; **30**: 147-51.
4. Foster GT, Chetty KG, Mahutte K, Kim JB, Sasse SA. Hemoptysis due to migration of a fractured Kirschner wire. *Chest* 2001; **119**: 1285-6.
5. Goodsett JR, Pahl AC, Gaspy JN, Schapira MM. Kirschner wire embolization to the heart: an unusual cause of pericardial tamponade. *Chest* 1999; **115**: 291-3.
6. Chou NS, Wu MH, Chan CS, Lai WW, Lin MY. Intrathoracic migration of Kirschner wires. *J Formos Med Assoc* 1994; **93**: 974-6.
7. Lyons FA, Rockwood Jr CA. Migration of pins used in operations on the shoulder. *J Bone Joint Surg Am* 1990; **72**: 1262-7.
8. Fowler AW. Migration of a wire from the sternoclavicular joint to the pericardial cavity. *Injury* 1981; **13**: 261-2.
9. Ippolito E, Tudisco C, Farsetti P, Caterini R. Fracture of the humeral condyles in children: 49 cases evaluated after 18-45 years. *Acta Orthop Scand* 1996; **67**: 173-8.
10. Thomas DP, Howard AW, Cole WG, Hedden DM. Three weeks of Kirschner wire fixation for displaced lateral condylar fractures of the humerus in children. *J Pediatr Orthop* 2001; **21**: 565-9.
11. Kumar R, Kiran EK, Malhotra R, Bhan S. Surgical management of the severely displaced supracondylar fracture of the humerus in children. *Injury* 2002; **33**: 517-22.
12. McLauchlan GJ, Cowan B, Annan IH, Robb JE. Management of completely displaced metaphyseal fractures of the distal radius in children. A prospective, randomised controlled trial. *J Bone Joint Surg Br* 2002; **84**: 413-7.
13. O'Hara LJ, Barlow JW, Clarke NM. Displaced supracondylar fractures of the humerus in children. Audit changes practice. *J Bone Joint Surg Br* 2000; **82**: 204-10.
14. Mohan N, Hunter JB, Colton CL. The posterolateral approach to the distal humerus for open reduction and internal fixation of fractures of the lateral condyle in children. *J Bone Joint Surg Br* 2000; **82**: 643-5.
15. Shim JS, Lee YS. Treatment of completely displaced supracondylar fracture of the humerus in children by cross-fixation with three Kirschner wires. *J Pediatr Orthop* 2002; **22**: 12-6.
16. Kurer MH, Regan MW. Completely displaced supracondylar fracture of the humerus in children. A review of 1708 comparable cases. *Clin Orthop* 1990; **256**: 205-14.
17. Cheng JC, Lam TP, Shen WY. Closed reduction and percutaneous pinning for type III displaced supracondylar fractures of the humerus in children. *J Orthop Trauma* 1995; **9**: 511-5.
18. Pirone AM, Graham HK, Krajchich JI. Management of displaced extension-type supracondylar fractures of the humerus in children. *J Bone Joint Surg Am* 1988; **70**: 641-50.
19. Cardona JI, Riddle E, Kumar SJ. Displaced fractures of the lateral humeral condyle: criteria for implant removal. *J Pediatr Orthop* 2002; **22**: 194-7.
20. Leet AI, Frisancho J, Ebramzadeh E. Delayed treatment of type 3 supracondylar humerus fractures in children. *J Pediatr Orthop* 2002; **22**: 203-7.
21. Leet AI, Young C, Hoffer MM. Medial condyle fractures of the humerus in children. *J Pediatr Orthop* 2002; **22**: 2-7.
22. Stahl S, Schwartz O. Complications of K-wire fixation of fractures and dislocations in the hand and wrist. *Arch Orthop Trauma Surg* 2001; **121**: 527-30.
23. Botte MJ, Davis JL, Rose BA, von Schroeder HP, Gellman H, Zinberg EM *et al*. Complications of smooth pin fixation of fractures and dislocations in the hand and wrist. *Clin Orthop* 1992; **276**: 194-201.
24. Stern PJ, Fulton DB. Distal interphalangeal joint arthrodesis: an analysis of complications. *J Hand Surg Am* 1992; **17**: 1139-45.
25. Starker I, Eaton RG. Kirschner wire placement in the emergency room. Is there a risk? *J Hand Surg Br* 1995; **20**: 535-8.
26. Green SA. Complications of pin and wire external fixation. *Instr Course Lect* 1990; **39**: 219-28.
27. Loncan LI, Sempere DF, Ajuria JE. Brown-Sequard syndrome caused by a Kirschner wire as a complication of clavicular osteosynthesis. *Spinal Cord* 1998; **36**: 797-9.
28. Asavamongkolkul A, Ruangsetakit C. False aneurysm of the brachial artery in supracondylar fracture treated with Kirschner wire fixation: a case report. *Injury* 2001; **32**: 256-7.
29. Fang RH, Chang TL. Watch out for the K-wire: painful experiences in two cases. *Br J Plast Surg* 2002; **55**: 698-9.
30. Gosens T, Bongers KJ. Neurovascular complications and functional outcome in displaced supracondylar fractures of the humerus in children. *Injury* 2003; **34**: 267-73.
31. Rasool MN. Ulnar nerve injury after K-wire fixation of supracondylar humerus fractures in children. *J Pediatr Orthop* 1998; **18**: 686-90.
32. Ikram MA. Ulnar nerve palsy: a complication following percutaneous fixation of supracondylar fractures of the humerus in children. *Injury* 1996; **27**: 303-5.
33. Royce RO, Dutkowsky JP, Kasser JR, Rand FR. Neurologic complications after K-wire fixation of supracondylar humerus fractures in children. *J Pediatr Orthop* 1991; **11**: 191-4.
34. Fambrough RA, Green DP. Tendon rupture as a complication of screw fixation in fractures in the hand. A case report. *J Bone Joint Surg Am* 1979; **61**: 781-2.
35. Gibbons CL, Woods DA, Pailthorpe C, Carr AJ, Worlock P. The management of isolated distal radius fractures in children. *J Pediatr Orthop* 1994; **14**: 207-10.