Use of ketamine sedation for the management of displaced paediatric forearm fractures

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AIM
To determine if ketamine sedation is a safe and cost effective way of treating displaced paediatric radial and ulna fractures in the emergency department.

METHODS
Following an agreed interdepartmental protocol, fractures of the radius and ulna (moderately to severely displaced) in children between the age of 2 and 16 years old, presenting within a specified 4 mo period, were manipulated in our paediatric emergency department. Verbal and written consent was obtained prior to procedural sedation to ensure parents were informed and satisfied to have ketamine. A single attempt at manipulation was performed. Pre and post manipulation radiographs were compared to assess for any improvement in alignment. The patients were observed for 4 h post-procedure. The procedures were performed between August 2014 and May 2015.

RESULTS
The study included 12 patients (8 boys and 4 girls) with a mean age of 9.3 years (range, 2.5–16.8 years). All patients were sedated with ketamine and were able to tolerate the procedure without any adverse events. The mean time to manipulation was 15 min (range, 5–30 min). Post-procedural imaging showed an improvement in alignment in 9 of 12 fractures (75%). All patients were discharged home the same day without any complications.

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manipulation radiographs were requested and assessed to ensure adequacy of reduction. Parental satisfaction surveys were collected after the procedure to assess the perceived quality of treatment. After closed reduction and cast immobilisation, patients were then followed-up in the paediatric outpatient fracture clinic and functional outcomes measured prospectively. A cost analysis compared to more formal manipulation under a general anaesthetic was also undertaken.

RESULTS
During the 4 mo period of study, 10 closed, moderate to severely displaced fractures were identified and treated in the paediatric emergency department using our ketamine sedation protocol. These included fractures of the growth plate (3), fractures of both radius and ulna (6) and a single isolated proximal radius fracture. The mean time from administration of ketamine until completion of the moulded plaster was 20 min. The mean time interval from sedation to full recovery was 74 min. We had no cases of unacceptable fracture reduction and no patients required any further manipulation, either in fracture clinic or under a more formal general anaesthetic. There were no serious adverse events in relation to the use of ketamine. Parents, patients and clinicians reported extremely favourable outcomes using this technique. Furthermore, compared to using a manipulation under general anaesthesia, each case performed under ketamine sedation was associated with a saving of £1470, the overall study saving being £14700.

CONCLUSION
Ketamine procedural sedation in the paediatric population is a safe and cost effective method for the treatment of displaced fractures of the radius and ulna, with high parent satisfaction rates.

Key words: Paediatrics; Forearm fractures; Displaced fractures; Ketamine; Salter Harris; Procedural sedation

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Core tip: Displaced paediatric forearm fractures can be safely and effectively treated in the emergency department with ketamine procedural sedation.

Wiik AV, Patel P, Bovis J, Cowper A, Pastides PS, Hulme A, Evans S, Stewart C. Use of ketamine sedation for the management of displaced paediatric forearm fractures. World J Orthop 2018; 9(3): 50-57. Available from: URL: http://www.wjgnet.com/2218-5836/full/v9/i3/50.htm DOI: http://dx.doi.org/10.5312/wjo.v9.i3.50

INTRODUCTION
Fractures of the radius and ulna account for 18% to 40% of all fractures in children[1,2]. They are the most common childhood fracture presenting to the paediatric emergency department (ED), with population studies suggesting that the incidence is on the rise throughout the world[3,4]. The majority are treated in the ED with closed reduction and immobilisation in a cast or a splint[5,6]. An arc of rotation of 100 degrees, split evenly between pronation and supination is accepted as normal[7]. The goal of treatment is to restore appropriate length and alignment so normal forearm rotation can return after healing[8]. Simple closed reduction and temporary stable immobilisation is the standard of care sought for these fractures as they generally heal well and surgical fixation doesn’t come without risk[9]. The provision of closed reduction can be problematic as there are variations in treatment practice as result of hospital resources, local policy and experience[10,11]. Despite this, a safe and optimal level of analgesia should be achieved before manipulation to avoid unnecessary distress to the child and to ensure a favourable outcome[12]. Simple analgesia such as paracetamol and non-steroidal anti-inflammatory drugs, along with intra-nasal opiates and nitrous oxide may be sufficient and have been shown to be an effective treatment in the ED[13]. However formal ED procedural sedation is an attractive alternative as it offers a greater opportunity to deliver the optimal fracture reduction and cast application[14]. Sedation in the ED is particularly helpful if the fracture pattern is unstable and requires complex traction manoeuvres to achieve adequate correction[14]. Providing complete treatment in the ED and avoiding theatres would negate the economic and psychosocial impact on the child and family if they were admitted into hospital[15,16]. It also has been shown to be more cost-effective to society, which is important in times of economic austerity[17].

There are a variety of classes of procedural sedation drugs used in the United Kingdom[18]. The most popular include opioids, benzodiazepines, propofol and ketamine[18]. Ketamine is the only drug that does not routinely interfere with protective airway reflexes and spontaneous respiration[18]. Ketamine is also the most complete agent as it produces amnesia, anxiolysis and profound analgesia[19]. This drug was first used in humans in the 1960[20]. It was used extensively in the Vietnam war in the 1970s for surgical anaesthesia due to its good safety profile[21]. Its widespread application in paediatric procedural sedation was developed in the 1990s following the work of Green et al[22-23]. Over the last three decades it has become one of the most widely used sedative agents in the ED[24,25]. It acts as a dissociative agent that non-competitively blocks NDMA receptors[26]. Traditionally the dose required is 1-2 mg/kg, administered via slow intravenous infusion and can be combined with opioids and benzodiazepines[24].

The aim of this clinical practice study was to determine if ketamine is a safe and cost effective way of treating displaced fractures of the radius and ulna in children.

MATERIALS AND METHODS
From May to September 2017, we prospectively evaluated
a new ketamine protocol (Figure 1) for paediatric ED procedural sedation at Chelsea and Westminster Hospital (CWH). All eligible children with significantly displaced or unstable fractures of the radius and ulna who presented to CWH ED during daylight weekday hours that needed closed reduction and moulded casting were included. The service improvement project was registered locally (QIP# LA353) to follow good clinical governance practice guidelines.

**Treatment protocol**

Following triage all children presenting to CWH ED with a suspected fracture of the radius and ulna undergo orthogonal anterior-posterior and lateral radiography. The radiographs are then screened by an ED doctor or triage nurse; if significant malalignment is identified the on-call orthopaedic registrar is notified. If the fracture is deemed suitable for manipulation using sedation the orthopaedic registrar and paediatric ED specialist explain the procedure to the child and parent/legal guardian. Counselling is given prior to obtaining written consent to ensure that the family is happy with the proposed sedation plan. They are advised that other treatment options are available if they wish. The inclusion criteria is any child below the age of 16 years with a significantly displaced or unstable fracture of the radius and/or ulna. Plain radiographs are demonstrated as examples of the nature of these fractures. Exclusion criteria included open fractures, ASA greater than 2, under 18 mo of age, any airway abnormality, acute systemic illness, previous adverse anaesthetic reactions, raised intracranial pressure, and/or bowel obstruction.

Informed written consent is taken and final neurovascular assessment is documented. The weight of the child is measured before he or she is taken to a quiet room for ketamine sedation and closed reduction. The parent/legal guardian is given the option to stay with the child for support and comfort. The team consists of a paediatrician, a specialist ED trainee/consultant with ketamine sedation experience, and an orthopaedic registrar. Blood pressure, pulse, respiratory rate and oxygen saturation are monitored and recorded. An alert is sent to an anaesthetic consultant that the procedure is about to start in case of serious adverse event (SAE) occurs. A sedation checklist is completed.

To start 1 mg/kg of ketamine is given through a peripheral intravenous cannula normally in the antecubital fossa or dorsum of the hand of the contralateral upper limb. After a period of 3 min the child’s vitals are rechecked. If the child appears to be sedated a gentle manipulation is attempted. If they are not adequately sedated, a top-up of 0.5 mg/kg is administered. Manipulation is performed; when the position is deemed to be satisfactory a stockinette is placed over the arm followed by...
There were no serious adverse events. Vomiting was 1.5 mg/kg to achieve appropriate analgesia and sedation. Two children required topping up to procedural sedation. All children had successful side. There were no cases of compartment syndrome or 6 fractures on the left side and 4 fractures on the right mean age was 8 years (range 2.2-14.5). There were indirect trauma, the majority being due to a fall on an outstretched hand. There were 8 boys and 2 girls. The included in the 4 mo time period. All ten were due to injury, time of procedure, sedation or reduction outcomes were documented. Consent forms were kept in the patient files. Pre and post reduction radiographs were taken from our departmental picture archiving and communication systems (PACS). Absolute angulation measurements were taken from the lateral radiographs using angle measuring tool (SECTRA) and measured by AW and PP. A repeated measure $t$-test was utilised to detect if a difference was made. A significance level was set to $\alpha = 0.005$ due to small numbers. The results were then compared to the best available evidence regarding acceptable reduction parameters for different fracture levels of the forearm[27]. Parental satisfaction was assessed using a validated satisfaction score[28].

Follow-up
Patients are seen in a paediatric fracture clinic 1 and 2 wk after manipulation when further radiographs are performed. If alignment is maintained the child is reviewed 3-6 wk later for removal of cast and repeat radiographs. A comprehensive examination is performed at this stage particularly looking for any obvious deformity, range of motion and for clinical evidence of fracture union. If union is felt to be insufficient a cast may be re-applied or splint provided. The child is reviewed 4-6 wk later for a final check. At the point of cast removal advice is given to avoid contact sport for a period deemed appropriate to allow for the bone to strengthen in accordance to Wolff’s law[26].

Statistical analysis
All patient data was anonymised. All hospital medical record numbers were retained in the paediatric ED database. Patient demographics, site and nature of injury, time of procedure, sedation or reduction outcomes were documented. Consent forms were kept in the patient files. Pre and post reduction radiographs were taken from our departmental picture archiving and communication systems (PACS). Absolute angulation measurements were taken from the lateral radiographs using angle measuring tool (SECTRA) and measured by AW and PP. A repeated measure $t$-test was utilised to detect if a difference was made. A significance level was set to $\alpha = 0.005$ due to small numbers. The results were then compared to the best available evidence regarding acceptable reduction parameters for different fracture levels of the forearm[27]. Parental satisfaction was assessed using a validated satisfaction score[28].

RESULTS
Demographics
A total of 10 closed unilateral forearm fractures were included in the 4 mo time period. All ten were due to indirect trauma, the majority being due to a fall on an outstretched hand. There were 8 boys and 2 girls. The mean age was 8 years (range 2.2-14.5). There were 6 fractures on the left side and 4 fractures on the right side. There were no cases of compartment syndrome or neurovascular compromise. All children had successful procedural sedation. Two children required topping up to 1.5 mg/kg to achieve appropriate analgesia and sedation. There were no serious adverse events. Vomiting was the most common adverse event, seen in 3 children. All were treated definitively at time of injury and required no further manipulation. No patients were lost to follow-up and all patients reported excellent functional outcomes at discharge as guided by Price et al[28]. Figures 2-4 (A-D) demonstrate the variety of fracture types and fracture reduction result.

Radiographic results
There were three Salter Harris II fractures of the distal radius, four fractures of the distal third of the radius and/or ulna, two fractures of the mid-shaft of the radius and/or ulna and one fracture of proximal third of the radius. The mean dorsal angulation prior to reduction was 45 degrees (range 17-80). The mean angulation after reduction was 6 degrees (0-15) an improvement that reached statistical significance ($P < 0.001$). Following reduction all fractures were within the parameters recommended by Noonan and Price as acceptable[27]. One patient had an over correction going from a 45 degrees dorsal angulation to 15 degrees of volar angulation, however there was no functional deficit at discharge.

Length of stay
The mean time from fracture diagnosis to sedation administration was 181 min (range 129-234). The mean time to completion of cast application was 20 min (range 7-35). The mean time from sedation to full recovery was 74 min (range 45-120). The mean interval between pre-reduction and post-reduction radiographs was 198 min (range 91-370 min). The mean length of stay in the ED department from arrival to discharge was 311 min (range 213-446).

Cost analysis of ketamine vs general anaesthesia in theatres
In our trust the health resource group (HRG) code for general anaesthesia in paediatric theatres is £1620 per child. The cost for procedural sedation with ketamine in the paediatric ED was £150 per child. The cost for procedural sedation with ketamine was calculated to give a fair comparison. The cost saving is £1470 per child without the addition of cost for admission and loss of earning to the parent/legal guardian if they had to stay with the child. The minimum total financial savings for these 10 children was £14700.

Parental satisfaction questionnaire
The validated sedation satisfaction score was out of 10, with 0 being not at all and 10 being very satisfied[27]. The mean satisfaction score for all questions was 9.6. The individual scores for each item is seen in Table 1. A score of 10 was the most common result for each questionnaire item.

DISCUSSION
The use of ketamine for procedural sedation in the ED
in the developed world is gaining popularity\textsuperscript{(19,24)}. In the past few years, there is a growing body of evidence supporting its use for successful procedural sedation with a good safety and efficacy profile\textsuperscript{(29,30)}. Serious adverse events are low with the largest prospective cohort study to date reporting a 1.1% risk with no deaths in 6295 children. Vomiting (5.2%) and oxygen desaturation (5.6%) were the most common adverse

Figure 2  Lateral and anteroposterior radiographs of a Salter Harris II distal radius fracture before (A, B) and after reduction (C, D).

Figure 3  Lateral and anteroposterior radiographs of a midshaft radius and ulna fracture before (A, B) and after reduction (C, D).
event found in this multi-centre study\textsuperscript{[24]}. With that risk being further reduced if no other sedatives, such as propofol or fentanyl, were used in conjunction. Earlier works by Green et al\textsuperscript{[31]}, support these findings as they found 3.9\% of children having respiratory adverse events and 8.4\% having vomiting. Furthermore they found that co-administering drugs (anticholinergics and benzodiazepines), which were to reduce the risk, in fact made them worse\textsuperscript{[31]}.

In our small study, we found no serious adverse events but three children had vomiting. High parental satisfaction scores in this pilot study demonstrate its acceptance amongst the families whose children had procedural sedation. All children had definitive reduction and stabilisation which resulted in an excellent functional outcome. This is contrary to a recent study comparing ketamine vs propofol for closed reduction of paediatric both bone forearm fractures which found 35\% and 48\% unacceptable alignment respectively at 4 wk\textsuperscript{[32]}. However their institution used a splint unlike ours which used a completed moulded cast to maintain reduction. An explanation which they admittedly acknowledge\textsuperscript{[32]}. This finding is supported by another recent study that found only 8.8\% children had displaced to an unacceptable standard if a moulded cast was used\textsuperscript{[13]}. An outcome which is impressive considering only Entonox and intranasal diamorphine was used for reduction analgesia\textsuperscript{[13]}. Nevertheless our result reinforces the finding that ketamine can give effective pain relief and sedation to allow thorough manipulation that resulted in fractures that were reduced and immobilised appropriately. The only major disadvantage we found with ketamine in our paediatric ED was the length of stay which was longer than normal. It was 5 h and 11 min which is beyond our National Health Service 4-h target. A target which was met using Entonox and intranasal diamorphine with a mean time of 3 h and 51 min\textsuperscript{[13]}. Still it is a parameter which can be improved as the greatest cause of lost

| Questionnaire item                          | Mean   | Range | Percent answering “10” |
|--------------------------------------------|--------|-------|-------------------------|
| Preparation and instruction given          | 9.86   | 9-10  | 85.7                    |
| The care given by nurse pre-procedure      | 9.43   | 8-10  | 71.4                    |
| The care given by doctor pre-procedure     | 9.86   | 9-10  | 85.7                    |
| The suitability of environment              | 9.57   | 8-10  | 71.4                    |
| The experience of the child                 | 8.57   | 3-10  | 71.4                    |
| The care given by the nurse post-procedure | 10     | 10    | 100                     |
| The care given by doctor post-procedure    | 9.86   | 9-10  | 85.7                    |
| Overall parent satisfaction                 | 9.71   | 9-10  | 71.4                    |
Ketamine for displaced paediatric forearm fractures

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In conclusion, ketamine sedation for children is safe and cost-effective for treating displaced fractures of the radius and ulna, it is associated with a high level of satisfaction.

**ARTICLE HIGHLIGHTS**

**Research background**

Children forearm fractures account for up to 40% of fractures that present to the emergency department (ED), majority which could be managed there.

**Research motivation**

This study improved the quality of care given to children with deformed forearm fractures in the ED.

**Research objectives**

The main aim of this quality improvement project was to determine if ketamine sedation is a safe and cost-effective way of treating deformed paediatric forearm fractures in the ED.

**Research methods**

Over a set 4 mo period we prospectively evaluated a new ketamine protocol for paediatric ED procedural sedation. All eligible children with significantly displaced or unstable fractures of the radius and ulna that presented during daylight weekday hours that needed closed reduction and moulded casting were included.

**Research results**

A total of 10 forearm fractures with a mean 45° angulation deformity were definitively treated in the ED with ketamine procedural sedation. The cost saving was £1470 for each child compared if the patient was taken to theatre. Overall mean parental satisfaction was 9.6 out of 10.

**Research conclusions**

Ketamine procedural sedation in the paediatric population is a safe and cost-effective way of treating deformed paediatric forearm fractures.

**Research perspectives**

Majority of paediatric forearm fracture, irrespective of displacement, can be treated in the ED as long as the fracture pattern is reducible and can be maintained safely in a moulded cast for the duration of its healing.

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March 18, 2018 | Volume 9 | Issue 3 | WJO | www.wjgnet.com

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P- Reviewer: Liu JY  S- Editor: Wang JL  L- Editor: A  E- Editor: Li D
