Anatomical landmarks in the paediatric distal radius: a new method for measuring epiphyseal height

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Anatomical landmarks in the paediatric distal radius: a new method for measuring epiphyseal height

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Abstract
Purpose Elastic stable intramedullary nailing for fixation of paediatric forearm fractures has become the preferred method of osteosynthesis. The aim of the study was to develop a method for finding the correct entry point in the distal radius of children of all ages as a distance from the radial styloid, a landmark which is readily palpable at the wrist.
Method MRI scans of the wrist in 19 children aged 2–7 years (mean 5) were reviewed. We noted that the proximal edges of the ossific nucleus of capitate and the tip of the radial styloid were at the same vertical height from the physis. This allowed us to review 519 wrist radiographs of children aged 2–14 years (mean 7.98) to measure the epiphyseal height, as the radial styloid does not ossify until the age of 14 years.
Results The epiphyseal height had a mean of 16.67 mm (13–21 mm). The epiphyseal height in boys was greater than the girls by a mean of 1.2 mm (p < 0.0005).
Conclusion For the absolute safe distance, we recommend an insertion site 40 mm proximal to the tip of the radial styloid, which is safe in all children with an open distal radial physis. This simple and reproducible method allows the identification of the insertion site for the nail with only the minimal use of imaging.

Keywords Distal radius · Distal radius epiphysis · Forearm fractures · Intramedullary nailing · Elastic nailing forearm fractures · Image intensifier

Introduction
Diaphyseal forearm fractures are common injuries in childhood, accounting for up to 10% of fractures in this age group [3]. Most can be treated by reduction and cast immobilisation with excellent results. Malunions, however, exhibit a poor potential for spontaneous remodelling. Even minor angular or rotational deformities can result in a block to pronation and supination [18]. This is functionally disabling for the child, hence osteosynthesis has become the method of choice for unstable and displaced, diaphyseal fractures of the forearm [1, 11–14]. Although there are several techniques for osteosynthesis (external fixator, plating, K-wires), elastic stable intramedullary nailing (ESIN) has become the method of choice. It was originally described by Jurado in 1977 [8] and later popularised by Lascombes et al. [9] from the University of Nancy. This technique has demonstrated excellent results in restoring function and range of motion of the forearm. It is also versatile and may be employed in the treatment of refractures [10, 16]. This method of osteosynthesis is performed with a minimally invasive technique. It provides a better cosmetic results, shorter operative time [2] and similar functional results to the traditional open-plating technique [12].

The correct entry point for the insertion ESIN in the distal radius is 2 cm proximal to the distal radial physis [17] in order to avoid injury to the perichondral ring of Lacroix during insertion or subsequent removal. It is, therefore, important to know the exact location of the physis and this is usually achieved by intraoperative imaging. A significant
proportion of imaging time (15%) is utilised for this purpose [6]. The tip of the radial styloid is a prominent landmark which can be located without the use of imaging.

The purpose of this study was to develop a simple and consistent method for finding the correct entry point for nail insertion in the distal radius for children of all ages as a distance from the radial styloid, a landmark which is readily palpable at the wrist, thus reducing the intraoperative radiation dose.

**Patients and methods**

The radial styloid remains cartilaginous until the age of 14, it is, therefore, not possible to visualise it on radiographs prior to this age. In the first part of this study, we analysed distal radius and wrist MRI scans from 19 children aged between 2 and 7 years (6 male and 13 females). The scans were performed with the forearm and wrist in the neutral position taking care to avoid radial or ulnar deviation. The maximum vertical height of the radial epiphysis in the coronal plane was determined on the coronal slices of the T1-weighted sequences (Fig. 1). We measured the maximum epiphyseal height as the vertical distance between two lines drawn at right angles to the anatomical axis of the radius, one at the level of the physis and the other at the level of the tip of the radial styloid (h1). We also measured the vertical distance between the physis and a line drawn at right angles to the anatomical axis of the radius at the level of the proximal edge of the ossific nucleus of capitate (h2) (Fig. 2).

We found a consistent relation between the proximal extent of the ossific nucleus of capitate and the radial styloid. The ossific nucleus of capitate is present from the age of two and its proximal aspect is at the level of the tip of the radial styloid. Then, this allowed us to perform these measurements on wrist radiographs where the ossific nucleus of capitate was visible.

Fifty standardised anteroposterior distal forearm radiographs were initially analysed on two separate occasions by one of the investigators in order to quantify intra-observer variability of the measurements. A further 50 standardised anteroposterior distal forearm radiographs were examined by two independent investigators to establish inter-observer variability. The difference between the two measurements of the same radiographs was recorded and the mean and standard deviation of the variation calculated.

Five-hundred and nineteen standardised anteroposterior distal forearm radiographs of 519 children (264 male, 255 female) between the ages 2 and 14 years were analysed. All radiographs displaying deformities and acute injuries of the wrist were excluded. We measured the vertical distance between two lines drawn at right angles to the anatomical axis of the radius, one at the level of the physis and the other at the level of the proximal edge of the ossific nucleus of capitate (h2) (Fig. 2).

All the measurements were performed in millimetres. Statistical analyses were performed with SPSS® Statistics 17.0 (IBM Headquarters, Chicago, IL, USA). Statistical significance was defined as \( p < 0.05 \). All data corresponded to a normal distribution. Pearson correlation coefficients were calculated to establish the correlation between the children’s age and the height of the epiphysis. Unpaired \( t \) tests for the mean were performed to establish whether a correlation between the height of the epiphysis and the gender or side exists.
Results

The 19 MRI scans were of wrists of 19 children (6 male and 13 female) with a mean age of 5 years (range 2–7). The mean epiphyseal height from the tip of the radial styloid (h1) was 13 mm (range 9–15 mm). The mean epiphyseal height from the proximal edge of the ossific nucleus of capitate (h2) was 14 mm (range 11–16 mm). The mean difference between h1 and h2 was 1 mm (range 0–2 mm) (Table 1).

The mean intra-observer variation was 1.2 mm (SD ± 0.9) and the mean inter-observer variation was 1.4 mm (SD ± 1.1) for the measurements of epiphyseal height from the proximal edge of the ossific nucleus of capitate on wrist radiographs. These values of negligible clinical relevance, the subsequent measurements were, therefore, performed by one observer.

Five-hundred and nineteen radiographs of the distal radius and wrist of 519 children (264 male, 255 female) with a mean age of 7.98 years (range 2–14) were analysed. 255 images were of the right and 264 images were of the left distal radius. The mean epiphyseal height (h2) was 16.7 mm (range 13–21 mm) (Table 2). These data conformed to a normal distribution (Fig. 3). There was significant positive correlation (Pearson correlation coefficient = 0.556) between the children’s age and epiphyseal height (Fig. 4; Table 3). We also found an association between gender and epiphyseal height with the male epiphyseal height being greater than the female by a mean of 1.2 mm (p < 0.0005). There was no statistically significant association between side and epiphyseal height (p = 0.5).

Table 1 MRI: age of the children, vertical distance between proximal aspect of the ossific nucleus of capitate and the tip of the radial styloid

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean</th>
<th>Median</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>5</td>
<td>6</td>
<td>1.76</td>
<td>2</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>h2: Capitate–Physis (mm)</td>
<td>19</td>
<td>14</td>
<td>14</td>
<td>1</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td>h1: Radial styloid–Physis (mm)</td>
<td>19</td>
<td>13</td>
<td>13</td>
<td>2</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>Difference h1−h2 (mm)</td>
<td>19</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2 Measurements of the epiphyseal height on distal forearm radiographs

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean</th>
<th>Median</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>7.98</td>
<td>7.67</td>
<td>3.56</td>
<td>2.03</td>
<td>14.41</td>
<td></td>
</tr>
<tr>
<td>Epiphyseal height (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>264</td>
<td>17.05</td>
<td>17</td>
<td>1.425</td>
<td>13</td>
<td>21</td>
</tr>
<tr>
<td>Female</td>
<td>255</td>
<td>16.27</td>
<td>16</td>
<td>1.334</td>
<td>13</td>
<td>19</td>
</tr>
<tr>
<td>Total</td>
<td>519</td>
<td>16.67</td>
<td>17</td>
<td>1.434</td>
<td>13</td>
<td>21</td>
</tr>
</tbody>
</table>

Fig. 3 Distribution of the epiphyseal height on distal forearm radiographs

Fig. 4 Scatter plot for Pearson correlation of between age and epiphyseal height
Table 3  Epiphyseal height by age group

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>2–4</th>
<th>4–6</th>
<th>6–8</th>
<th>8–10</th>
<th>10–12</th>
<th>12–14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>93</td>
<td>87</td>
<td>91</td>
<td>82</td>
<td>86</td>
<td>80</td>
</tr>
<tr>
<td>Mean epiphyseal height (mm)</td>
<td>15.5</td>
<td>16.0</td>
<td>16.7</td>
<td>17.3</td>
<td>17.0</td>
<td>17.8</td>
</tr>
<tr>
<td>SD</td>
<td>1.2</td>
<td>1.2</td>
<td>1.1</td>
<td>1.0</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Range (mm)</td>
<td>13–18</td>
<td>13–19</td>
<td>14–20</td>
<td>15–20</td>
<td>14–20</td>
<td>14–21</td>
</tr>
</tbody>
</table>

Discussion

In the first part of our study, we have described a relationship between the proximal edge of the ossific nucleus of capitare and the tip of the radial styloid. To our knowledge, this has not been previously described. In the 19 MRI scans analysed, this relationship remained consistent. Although there is a mean difference of 1 mm between the measurements, it is unlikely to be clinically significant. We liked to analyse a greater number of MRI scans, but this investigation was not performed frequently in this age group and the ethical and financial consideration surrounding MRI imaging of young children meant acquisition of further scans was not feasible. Once this radiological relationship had been delineated a much larger data set was compiled by examining radiographs.

ESIN has become a well-established operative procedure in the paediatric trauma surgery [1, 8, 9, 13]. Unstable and displaced diaphyseal forearm fractures in children between the ages of 2 and 14 years can be treated using this technique with excellent results [4, 9, 12, 17]. The removal of these implants is also technically less demanding than the plate removal and associated with less number of complications [15]. The insertion of intramedullary nails is dependent on intraoperative imaging which exposes the patient to ionising radiation [5–7]. Kraus et al. timed the use of an image intensifier during various manoeuvres of flexible nailing of forearm fractures. They demonstrated that, on average, the imaging time was 59.5 (8–222) s with 53% of the time spent passing the nail across the fracture and 15.3% of the imaging time identifying the correct entry site and inserting the nail [5, 6].

Our results show a significant correlation between epiphyseal height, age and gender. The positive correlation between increasing age and increasing epiphyseal height is not surprising. As children grow, so do their distal radial epiphysis, however, these differences are quite small. There is only a difference of 1.2 mm between mean epiphyseal heights of boys and girls, and the height of the epiphysis increases by an average of 3 mm from the youngest to the oldest subjects in this study population. These rather small differences are of questionable significance in clinical practice. The accuracy of our data is sufficient to allow us to recommend an absolute safe distance from the tip of the radial styloid for the insertion of ESINs into the radius. It is possible to reproducibly identify the position of the physis without the use of imaging. The mean distance of the physis from the tip of the radial styloid is 16.7 mm (13–21 mm). The insertion site for the nail should be 20 mm proximal to the physis [17] allowing a safe margin and avoiding any iatrogenic injury to the perichondral ring. The originators of the technique recommend a shorter distance of 1–1.5 cm proximal to the distal radial physis [8]. For the absolute safe distance, we recommend an insertion site 40 mm proximal to the tip of the radial styloid in the mid coronal plane on the radial border of the forearm. We feel it is safer to assume the height of the epiphysis to be at the upper limit of normal (21 mm) rather than the mean (16.6 mm). A safe point for the insertion of radial intramedullary nails is 40 mm from the tip of the radial styloid. By measuring 2 or 3 finger breadths (depending on the size of the surgeon’s fingers) or more accurately with a ruler from the tip of the radial styloid a safe entry point can be identified. This can then simply be checked by a single-pulsed image intraoperatively to confirm the safe distance from the physis, reducing the dose of ionising radiation.

Conflict of interest  The authors declare that they have no conflicts of interest.

References
