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Differences in childhood adiposity influence upper limb fracture site

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Abstract:

Introduction

Although it has been suggested that overweight and obese children have an increased risk of fracture, recent studies in post-menopausal women have shown that the relationship between obesity and fracture risk varies by fracture site. We therefore assessed whether adiposity and overweight/obesity prevalence differed by upper limb fracture site in children.

Methods

Height, weight, BMI, triceps and subscapular skinfold thickness (SFT) were measured in children aged 3-18 years with an acute upper limb fracture. Data was compared across three fracture sites (hand, forearm and upper arm/shoulder [UA]), and to published reference data.

Results

401 children (67.1% male, median age 11.71 years (range 3.54-17.27 years) participated. 34.2%, 50.6% and 15.2% had fractures of the hand, forearm and UA, respectively. Children with forearm fractures had higher weight, BMI, subscapular SFT and fat percentage z-scores than those with UA fractures (p<0.05 for all). SFT and fat percentage z-scores were also higher in children with forearm fractures compared to hand fractures, but children with hand and UA fractures did not differ. Overweight and obesity prevalence was higher in children with forearm fractures (37.6%) than those with UA fractures (19.0%, p=0.009). This prevalence was also higher than the published United Kingdom population prevalence (27.9%, p=0.003), whereas that of children with either UA (p=0.13) or hand fractures (29.1%, p=0.76) did not differ. These differences in anthropometry and overweight/obesity prevalence by fracture site were evident in boys, but not present in girls.

Conclusion

Measurements of adiposity and the prevalence of overweight/obesity differ by fracture site in children, and in particular boys, with upper limb fractures.

Highlights

- Adult fracture risk in obesity varies by fracture site, but this has not previously been investigated in children.
- Children with forearm fractures had higher BMI and fat percentage than children with upper arm fractures.
- Overweight and obesity were more prevalent in children with forearm arm fractures than upper arm and hand fractures.

1.   Introduction

Recent data suggests that 28% of children aged between 2 and 15 years in the United Kingdom (UK) are overweight or obese [1]. Fractures are common in childhood [2, 3], and many studies have suggested that overweight and obese children are at increased risk of sustaining a fracture [4-9] and fracture complications [10, 11]. However, this finding is not consistent in all studies [12-15].

In contrast to the observations in children, it was previously considered that obesity was protective against fracture in adults; however more recently it has been recognised that the risk varies by fracture site. Thus, in post-menopausal women, obesity is protective against hip and wrist fractures, but confers an increased risk for ankle, lower leg and humeral fractures, although the underlying mechanism for this difference in risk is not clearly understood [16-19]. There are few studies which have assessed fracture risk in overweight/obese (Ov/Ob) children stratified by fracture location, and these have tended to consider fracture site as either upper or lower limb. Adams et al. reported an increased risk of lower extremity, but not upper extremity, fractures in Ov/Ob children [4]. Similarly, in a study of children in Southern Italy, a greater proportion of children with lower compared to upper limb fractures were Ov/Ob [7].

The upper limb is the most common site of fracture in children, with incidence rates nearly four times that of lower limb fractures [3]. Whilst one study has assessed the relationship between Ov/Ob and fracture sites in the lower limb and found that this differed by body weight status [8], obesity prevalence by fracture site within the upper limb in children has not previously been investigated. We therefore sought to assess body composition and Ov/Ob prevalence in children who presented to a paediatric orthopaedic department with an acute upper limb fracture, and to determine whether these differed by fracture site.

1. Methods

Children aged 3-18 years attending the University Hospital Southampton NHS Foundation Trust children's orthopaedic outpatients were invited to participate if they had sustained an acute upper limb fracture within the preceding 60 days. All children who attend the hospital emergency department

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with a fracture are referred to the orthopaedic clinic for review. Fractures were confirmed by radiological reports. Thus children who had clinically suspicious fractures but no radiological evidence were not included. Data collection occurred over two winter periods: October 2012-April 2013 and October 2013-May 2014. Children were excluded if they had a medical condition known to increase fracture risk or were currently receiving oral steroids. The study was approved by the Portsmouth Research Ethics Committee. Written informed consent was obtained from a parent or guardian accompanying the child and assent was obtained from all children.

A parent/guardian questionnaire was used to obtain information on the date and mechanism of fracture, medical history and the child's ethnicity. Height was measured to the nearest 0.1cm using a Leicester Height measurer (Seca Ltd), and weight to the nearest 0.1kg using electronic scales (Seca Ltd). Weight was assessed in light clothing after removal of any plaster casts or limb splints. BMI was calculated as weight/height^2. Height, weight and BMI z-scores for age and sex were calculated using the British 1990 growth data [20, 21]. Overweight and obesity were defined as a BMI z-score $\geq$ 1.036 (85th centile) and $\geq$1.645 (95th centile), respectively. These definitions were chosen to allow comparison to the reported UK prevalence derived from the Health Survey for England [1]. Waist circumference, as a marker of central adiposity, was measured using a cloth tape at the mid-point between the costal margin and the iliac crest. British reference data was used to define a waist circumference $\geq$90th centile for age and sex in children over 5 years of age [22].

Triceps and subscapular skinfold thickness (SFT) measurements were performed on the non-dominant side of the body using a Holtain skinfold caliper (Holtain Ltd, Pembs., UK). Fat percentage was calculated from the triceps and subscapular SFT using the Slaughter equation [23]. In boys, the equation used is dependent on pubertal status. This was assessed using a pictorial questionnaire completed by the child and/or parent [24]. There are no published British reference data for SFT or the derived fat percentage. Therefore, SFT z-scores for age and sex were calculated using reference data obtained in the US National Health Examination Surveys and National Health and Nutrition Examination Surveys (NHANES) from 1963-1994 [25]. For participants aged over 5 years, fat

percentage z-scores for age and sex were calculated using reference data from NHANES 1999-2004 [26].

2.1   Statistical analysis

Fractures were divided into three sites according to the International Classification of Diseases-10: hand (phalanges, metacarpals and/or carpals), forearm (radius and/or ulna) and upper arm/shoulder (humerus, clavicle and/or scapula) [UA].   Differences in demographics and body composition between boys and girls were explored using t-tests and Mann-Whitney U test for normally and non-normally distributed variables, respectively, and across fractures sites using Kruskal-Wallis test and one way ANOVA with post-hoc Bonferroni correction. Chi-squared test was used to determine statistical significance for categorical variables.

We did not collect data from children who had not sustained fractures. Therefore to determine whether anthropometry and adiposity z-scores differed from the background population at each fracture site, a one sample t-test with an expected population mean of 0 was used. Furthermore, Ov/Ob prevalence was compared to the published prevalence for English children who had height and weight measured in the Health Survey for England 2012 (27.9% for all children, 27.9% for boys and 28.0% for girls) [1] using the chi-squared test.

All analysis was performed using SPSS version 21. A p-value of <0.05 was considered statistically significant. All data is reported as mean (95% confidence interval), unless otherwise stated.

3.   Results

3.1   Study participants

403 children participated in the study; however two were excluded from this analysis due to fractures in more than one of hand, forearm and UA. Of the 401 children included in the analysis, 269 (67.1%) were male and 374 (93.3%) were of white ethnicity. The median age at fracture was 11.71 years

(range 3.54-17.27 years), and time from fracture to study participation was 10 days (range 1-60 days). Boys (median age 12.74 years, range 3.54-17.27 years) were older than girls (median age 10.30 years, range 3.64-15.89 years, p<0.001).

137 (34.2%), 203 (50.6%) and 61 (15.2%) participants had fractures of the hand, forearm and UA, respectively. Participants with hand fractures (median age 13.42 years, range 3.54-17.08 years) were older than those with forearm fractures (median age 10.84 years, range 3.64-17.27 years, p<0.001) and UA fractures (median age 9.82 years, range 3.71-16.80 years, p<0.001). Age was similar for participants with forearm and UA fractures (p=0.30).

3.2   Injury mechanism

Table 1 details the mechanism of injury by fracture site. A greater proportion of UA fractures than hand or forearm fractures occurred due to falls from low heights. Sporting injuries accounted for a greater percentage of hand (40.1%) and UA fractures (34.4%) than forearm fractures (28.6%).

Table 1: Mechanism of fracture in children with upper limb fractures. Displayed as n (% of fracture site or % obesity status)

	Fracture site			Obesity status	
	Hand	Forearm	Upper arm/ Shoulder	Healthy Weight	Overweight or Obese
n	137	203	61	260	121
Fall from low height (<1m)	11 (8.0)	41 (20.2)	28 (45.9)	54 (20.8)	23 (19.0)
Fall from moderate height (1-3m)	3 (2.2)	44 (21.7)	7 (11.5)	35 (13.5)	15 (12.4)
Rollerskating/Cycling/Skiing/Skateboarding	10 (7.3)	35 (17.2)	2 (3.3)	28 (10.8)	17 (14.0)
During sports participation	55 (40.1)	58 (28.6)	21 (34.4)	86 (33.1)	39 (32.2)
Fighting	23 (16.8)	3 (1.5)	2 (3.3)	17 (6.5)	10 (8.3)
Fall from height >3m or downstairs	5 (3.6)	11 (5.4)	0 (0.0)	6 (2.3)	6 (4.9)
Pedestrian/Cyclist hit by vehicle	0 (0.0)	2 (1.0)	0 (0.0)	2 (0.8)	0 (0.0)
Crush injury or hit by large object	13 (9.5)	2 (1.0)	0 (0.0)	13 (5.0)	2 (1.6)
Other	20 (14.6)	7 (3.4)	1 (1.6)	19 (7.3)	9 (7.4)

3.3   Anthropometry and adiposity

Height, weight, triceps and subscapular skinfold thickness could not be measured in 3 (0.7%), 19 (4.7%), 56 (14.0%) and 63 (15.7%) children, due to a plaster cast or refusal. Fat percentage z-score was calculated for 257 children (18 children under 5 years of age at study participation, 56 did not have both triceps and subscapular SFT measured and 70 boys did not complete the pubertal staging questionnaire required to calculate fat percentage). Height, weight, BMI and SFT z-scores did not differ for children for whom fat percentage z-score was and was not calculated.

Height z-score was similar across the three fracture sites, but weight, BMI, SFT and fat percentage z-scores all differed (Table 2). Thus, children with forearm fractures had the highest z-scores for all adiposity measurements and children with UA fractures had the lowest z-scores. These were significantly different between children with forearm and UA fractures (Table 2). Triceps SFT, subscapular SFT and fat percentage z-scores were also significantly lower in the children with hand fractures compared to forearm fractures.

Table 2: Anthropometry and body composition in children with upper limb fractures. Displayed as mean (95% confidence interval), unless otherwise stated.

	Fracture site			Statistical significance			
	Hand	Forearm	Upper arm/Shoulder	P across groups	Hand vs Forearm	Hand vs Upper arm	Forearm vs Upper arm
N	137	203	61				
% Male	76.6	58.6	73.8	0.001	0.001	0.66	0.03
Age at fracture, years (median [range])	13.42 [3.54-17.08]	10.84 [3.64-17.27]	9.82 [3.71-16.80]	<0.001	<0.001	<0.001	0.30
Days from fracture to study participation (median [range])	10 [2-60]	10 [1-48]	11 [4-56]	0.57			
Height z-score	0.32 (0.14, 0.51)[b]	0.44 (0.29, 0.59)[c]	0.33 (0.07, 0.60)[a]	0.58			
Weight z-score	0.48 (0.30, 0.66)[c]	0.70 (0.55, 0.86)[c]	0.29 (-0.04, 0.61)	0.03	0.23	0.81	0.04
BMI z-score	0.41 (0.22, 0.60)[c]	0.68 (0.53, 0.83)[c]	0.16 (-0.16, 0.49)	0.004	0.09	0.48	0.006
Triceps SFT z-score	0.20 (0.05, 0.36)[a]	0.48 (0.35, 0.60)[c]	0.17 (-0.05, 0.39)	0.008	0.02	1.00	0.07
Subscapular SFT z-score	0.49 (0.08, 0.34)[c]	0.71 (0.60, 0.83)[c]	0.18 (-0.04, 0.41)	<0.001	0.05	0.06	<0.001
Fat % z-score	-0.07 (-0.25, 0.12)	0.22 (0.09, 0.36)[b]	-0.27 (-0.53, -0.01)[a]	0.002	0.03	0.71	0.005

(a) p<0.05 (b) p<0.01 (c) p<0.001 in comparison to a population mean of 0

When analysed separately, the findings were similar for males as to the whole cohort, whereas, there were no significant differences across the three fracture sites in any anthropometric or body composition parameter in females (Table 3).

Table 3: Anthropometry and body composition in children with upper limb fractures stratified by sex. Displayed as mean (95% confidence interval), unless otherwise stated.

	Male				**Female**			
	Hand	Forearm	Upper arm/ Shoulder	P across male fracture sites	Hand	Forearm	Upper arm/ Shoulder	P across female fracture sites
N (% of sex)	105 (39.0)	119 (44.3)	45 (16.7)		32 (24.2)	84 (63.6)	16 (12.1)	
Age at fracture, years (median [range)]	13.7 (12.0-14.7)	11.9 (9.4-13.5)[a]	9.9 (5.9-13.5)[a]	<0.001	11.6 (9.1-13.1)	9.9 (7.3-12.0)	7.4 (5.6-11.7)	0.01
Height z-score	0.39 (0.17, 0.60)	0.47 (0.27, 0.67)	0.21 (-0.13, 0.55)	0.40	0.10 (-0.28, 0.47)	0.40 (0.16, 0.64)	0.69 (0.42, 0.96)	0.14
Weight z-score	0.49 (0.28, 0.71)	0.75 (0.55, 0.94)	0.07 (-0.31, 0.45)[b]	0.003	0.44 (0.08, 0.79)	0.63 (0.38, 0.89)	0.97 (0.46, 1.48)	0.30
BMI z-score	0.39 (0.16, 0.62)	0.73 (0.54, 0.93)	-0.01 (-0.38, 0.36)[b]	0.001	0.48 (0.14, 0.83)	0.61 (0.37, 0.86)	0.69 (0.01, 1.38)	0.80
Triceps SFT z-score	0.17 (-0.01, 0.36)[b]	0.52 (0.37, 0.68)	-0.06 (-0.18, 0.31)[b]	0.002	0.31 (-0.01, 0.63)	0.41 (0.19, 0.63)	0.42 (-0.05, 0.89)	0.88
Subscapular SFT z-score	0.48 (0.32, 0.64)[b]	0.76 (0.63, 0.90)	0.07 (-0.17, 0.31)[a,b]	<0.001	0.53 (0.17, 0.89)	0.64 (0.44, 0.84)	0.44 (-0.07, 0.96)	0.66
Fat % z-score	-0.10 (-0.32, 0.12)[b]	0.30 (0.13, 0.48)	-0.48 (-0.09, 0.17)[b]	<0.001	0.03 (-0.33, 0.39)	0.13 (-0.08, 0.34)	0.10 (-0.41, 0.61)	0.90

(a) Significantly different from children with hand fractures, p<0.05 (b) significantly different from children with forearm fractures, p<0.05

Analysis to determine whether children with forearm fractures have increased adiposity, or those with UA fractures decreased adiposity compared to the background population, revealed that children with fractures of the forearm and hand had significantly greater height, weight, BMI, SFT (p<0.001 for all) and fat percentage z-scores (p=0.001) than would be expected based on the population distribution (Table 2). Conversely children with UA fractures did not differ from the population data, except for taller stature (p=0.013) and a lower mean fat percentage z-score (p=0.045).

3.4 Overweight and Obesity prevalence

16.8% of all participants were overweight and a further 15.0% obese. 38.6% of children over 5 years of age had a waist circumference >90th centile. Mechanism of injury was similar in Ov/Ob children to those with a healthy BMI (Table 1).

A greater proportion of children with forearm fractures were categorised as Ov/Ob (37.6%) than those with UA fractures (19.0%, p=0.009, Figure 1). Neither group differed from children with hand fractures. Similarly, more children with forearm fractures had a waist circumference >90th centile than children with UA fractures (Figure 1). As with the differences in anthropometry, the prevalence of overweight/obesity and waist circumference >90th centile by fracture site differed only in males and not females (Figure 1).

Figure 1: **Prevalence of overweight/obesity and waist circumference >90th centile in children with upper limb fractures according to fracture site.** The dotted line represents the prevalence of childhood overweight/obesity in the Health Survey for England 2012[1] with significant difference from this for each fracture site shown by the asterisks (*p<0.05, **p<0.01)
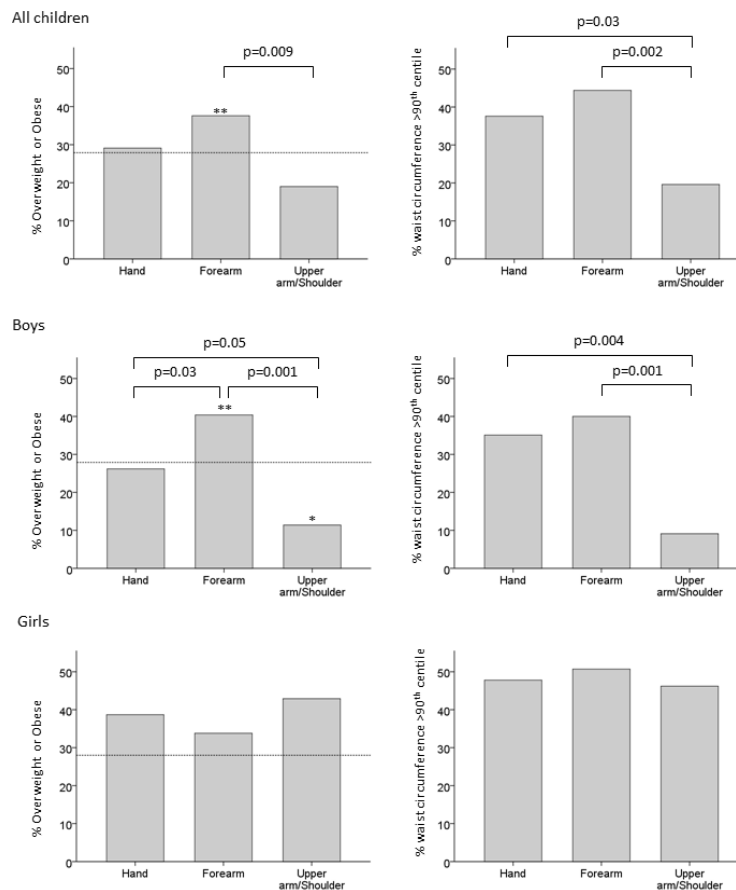
Overall, the prevalence of Ov/Ob was similar to the 2012 UK population prevalence of 27.9% (p=0.09). However, the prevalence in children with forearm fractures was significantly higher (p=0.003). Ov/Ob prevalence did not differ from the background population in children with hand (p=0.76) or UA fractures (p=0.13). In boys, the prevalence of Ov/Ob was significantly higher in those with forearm fracture and lower in UA fractures than the UK population prevalence (Figure 1). No significant differences were observed in girls.

3.5   Sensitivity analysis

In sensitivity analysis, we excluded 18 children who had either a high impact (road traffic accidents as pedestrian, cyclist or passenger in a vehicle, falls downstairs or from >3m, impacts with large objects or crush injuries, n=15) or unknown (n=3) mechanism of injury, but this did not alter the findings (data not shown).

4.0   Discussion

Childhood overweight and obesity has been associated with an increased risk of fracture [4-9], however it has not previously been demonstrated whether this is true for all fracture sites. In this cohort of children with upper limb fractures, Ov/Ob prevalence did not differ from that reported for the UK population. However, differences in body composition and the prevalence of Ov/Ob were observed across fracture sites. Thus, children with fractures involving the forearm were heavier and had higher BMI, skinfold thicknesses and fat percentage than children with fractures involving the UA or hand. Furthermore, the prevalence of Ov/Ob was significantly greater in children with forearm fractures than both children with UA fractures and in comparison to the UK population. These differences were only present in boys and not girls.

There are a number of limitations to our data. Firstly, we did not collect contemporary body composition on children without fractures. Therefore in order to delineate the direction of effect,

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anthropometric and adiposity measurements were compared to published population data. However, the British 1990 growth data is based on measurements collected from 1978-1990 [21] and the American skinfold thickness reference data on measurements from 1963-1994 [25]. Therefore, these data might not be representative of the current population. However, we additionally used the Health Survey for England 2012 estimate for the prevalence of childhood overweight and obesity [1], which is a more contemporary picture of the UK population. Nonetheless, future case-control studies are required to confirm our findings. Secondly, a number of children did have missing data due to the presence of plaster casts, and the time delay between fracture and study participation might have resulted in changes in weight and/or adiposity. However, it was felt inappropriate to undertake these measurements at the time of presentation with a fracture, and for some children it was not possible to remove casts to allow all measurements to be made. Nonetheless, children with missing data did not differ to those with data available. Furthermore the time from fracture to measurements was similar for all fracture sites, and only children who were recruited within 60 days of fracture were included to limit the inclusion of those who had been prevented from undertaking their usual levels of physical activity for long periods due to prolonged limb immobilisation. The use of questionnaire self-assessment to determine pubertal status is limited by the need for further validation of this approach. However our experience is that few children will consent to formal examination of pubertal staging for research and therefore this method was felt to be the most appropriate. The findings relating to body fat percentage z-scores however were consistent with the other anthropometric and skinfold thickness results. The use of Dual energy X-ray Absorptiometry (DXA) should also be considered in future work to provide a more detailed assessment of both whole body and regional body composition. Over 90% of children included in this study were of white ethnicity. This reflects the local population, but may limit the extrapolation to cohorts of children from other ethnic backgrounds. Finally, age and sex of the participants in each fracture group did differ. However, this reflects the known epidemiology of childhood fractures: the peak ages for humeral and clavicular fractures are younger than forearm fractures, and carpal fractures tend to occur later in childhood [3]. However, we assessed the differences in body composition using z-scores for age and sex, and this would therefore have accounted for these differences in age and sex.

Our findings demonstrate that children with forearm fractures have higher body weight and indices of adiposity than children with UA or hand fractures. We cannot be certain whether this reflects higher body weight and/or adiposity increasing the risk of forearm fracture, or conversely, whether greater adiposity is protective against UA or hand fractures. Indeed, 40% of UA fractures were caused by falls from low height and therefore would be considered low impact injuries [27]. As such, additional subcutaneous fat over the shoulder, upper arm and upper chest wall may protect against a fracture due to impacts at this site in more adipose children. However, comparison of our data to published reference data would suggest that children with forearm fractures are more adipose than the general population, whereas those with UA fractures did not differ apart from a lower fat percentage. Nonetheless, these findings are interesting as they contrast with that observed in older women, in whom higher BMI was protective against wrist fracture, but detrimental to fractures of the humerus [17, 16, 18, 19].

No previous study has considered differences in body composition in children with fractures across upper limb fracture sites. Kessler et al. assessed obesity in children with lower limb fractures and found that the risk of hip and femoral fracture was not increased in those who were overweight or moderately obese, but lower leg, ankle and foot fractures were [8]. Importantly, studies which have evaluated the relationship between BMI or Ov/Ob and fracture risk, either including all types of fractures or limited to the upper or lower extremity, have reported inconsistent findings: increased [4, 7], no different [4, 12, 14] and lower [15] fractures incidences in Ov/Ob children have been shown. The findings of this study can perhaps provide explanation for these differing conclusions in that if the relative proportion of fracture sites varies, this would alter the observed overall risk of fracture in overweight and obese children. Furthermore, we found that the differences in body composition and Ov/ob prevalence across fracture sites were only present in boys and not girls, although at all three fracture sites girls had higher weight and BMI z-scores than the background population. In a study of children managed in an Italian hospital, there was a higher prevalence of Ov/Ob in girls with forearm/elbow fractures compared to non-fracturing controls, but this was not observed in boys [7]. It is possible that the differences in body composition across fracture sites are only present in males, but

fewer girls than boys were included in this study, and therefore the power to detect a significant difference in girls will be lower. However, deficits in bone microarchitecture and strength at the distal radius have been found in girls with forearm fractures compared to non-fracturing controls, whereas no differences in boys were observed [28]. It is therefore possible that other factors, such as adiposity, have a greater influence on risk of fracture at the forearm in males compared to females, and underlie the findings of this study. Further confirmation of this sex disparity in larger cohorts is therefore required.

The mechanisms underlying these differences in body composition and Ov/Ob prevalence between children with forearm and UA or hand fractures are not clear. Indeed, in comparison to healthy weight children, Ov/Ob children have increased bone mineral density (BMD) and bone cross-sectional area [29, 30], but a recent study using high resolution peripheral quantitative computed tomography (HR-pQCT) found no difference in indices of bone strength at the distal tibia or radius in obese compared to lean children [31]. Thus the greater impact caused by a fall at higher body weight in obese children may increase the risk of fracturing. However, site-specific differences in bone strength within the upper limb are unlikely, although, to our knowledge, have not been formally investigated. Vitamin D deficiency is more common in overweight and obese children, however, there is no consistent evidence to support an association between vitamin D deficiency and fracture risk in childhood [32], and similarly, it is unlikely that this would lead to site specific differences. It is possible that body weight or adiposity contribute to the likelihood of fracture depending on mechanism of injury as these did differ between children with forearm and UA fractures, although overall fracture mechanisms were similar between healthy weight and overweight/obese children. In particular, a higher proportion of forearm fractures were caused by falls from moderate heights or moving apparatus (bicycles, rollerskates etc), and thus increased body weight falling on an outstretched arm might be more likely to result in forearm fracture in an overweight child than a healthy weight individual. Additionally, obese children also have poorer balance and perform less well on tests of motor function [33, 34]. Furthermore, Ma et al have demonstrated that children with forearm fractures score more poorly on tests of manual dexterity and dynamic balance than BMI-

matched controls, whereas children with UA and hand fractures did not differ from controls [35]. As such, poorer balance and motor skills in obese children might result in an injury mechanism which tends to cause forearm rather than other upper limb site fractures.

5.0   Conclusion

In conclusion, in this study we have demonstrated that boys with forearm fractures have higher indices of adiposity than boys with UA or hand fractures. Comparison to population data suggest that this is due to high adiposity in boys with forearm fractures, rather than low adiposity in those with UA fractures, but comparison to a contemporary control group in future studies is needed. This finding could explain the inconsistencies in reported risk of fracture in children with overweight and obesity.

6.0   Acknowledgements

7.0   Conflicts of Interest

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