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Appendicular fracture epidemiology of children and adolescents: A 10-year case review in Western Australia (2005 to 2015)

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MINI-ABSTRACT / SUMMARY

Fracture incidence data of Australian children and adolescents have not been reported in the literature. A ten-year case review of fracture presentations in Western Australia is provided. Between 2005 and 2015, fracture incidence increased relative to population growth. This is concerning, and interventions are urgently needed to reverse this trend.

ABSTRACT

Purpose: Fracture incidence in 0-16 year olds is high and varies between countries. Boys have a 1.5:1 ratio of fracture incidence compared to girls. There are no specific data for Australia. Western Australia is a state with unique geography and population distribution having only a single tertiary paediatric hospital (Princess Margaret Hospital, PMH, in Perth) managing the majority of children and adolescents with fractures in the Emergency Department (ED). The aims of this study were to characterize fracture presentations to PMH-ED and compare the incidence to population data. **Methods**: A database audit of fracture presentations between 2005-2015 for fracture rates with a sub-analysis for gender, fracture site and age and a comparison to Perth Metropolitan and Western Australian population data was performed. **Results**: Analysis included 31,340 presentations. Fracture incidence, adjusted for the annual population size, increased from 0.63% in 2005 to 0.85% in 2015 ($p < 0.001$). The winter months had a higher incidence of fractures than the summer months ($p = 0.081$). Males had a 1.5 times higher fracture incidence than females ($p < 0.001$), with upper limb fractures three times more common than lower limb fractures ($p < 0.001$). Fracture incidence increased with age until the early teenage years (15 years for males; 12 years for females) when a decline occurred. **Conclusions**: Increased fracture incidence in Western Australia between 2005 and 2015 identifies a concerning trend for bone health in children and adolescents.. Further research is needed to identify potential lifestyle factors that impact fracture incidence translating into evidence-based strategies to reverse these trends and improve bone health.

Key Words:

Bone, Population, Pediatric, Incidence, Audit.

INTRODUCTION

Up to 50% of boys and 40% of girls experience fractures during childhood and adolescence [1], with an overall fracture incidence per 10,000 persons (10^4) ranging from 120 to 361 with a male predominance [2,3], varying in magnitude across countries (Table 1). Scandinavian data for 0-16 year olds report boys and girls to have a 42% and 27% risk of fracture respectively [4]; whereas in the United Kingdom around 30% of boys and 19% of girls have fractures before 18 years of age [5]; illustrating a consistent 1.5:1 ratio of fracture incidence between boys and girls; the most common causes of which include falls, collisions and traffic accidents [6].

Fracture audits from European nations have shown that upper limb fractures represent 68% of fractures in children [7], with the forearm accounting for 27% to 45% of those [8], of which 23% to 35.8% affected the distal region [9,10]. However, the types and sites of fractures vary with age. For example, femur fractures are common early in life, but decrease substantially after the age of three [11]. These age–dependent changes in bone strength are partially determined by bone mass and geometry and influence fracture incidence [12-14]. Further factors include type of activity, e.g. participation in contact sports compared to non-contact sports, and body weight, with obesity in children associated with an impaired balance leading to a higher rate of falls and subsequent fractures [15]. Children with different ethnic backgrounds develop at differing rates, and have culture-specific physical activity patterns, which makes regional fracture audits necessary. However, no fracture audit of Australian children has been published to date.

No specific analyses exist in Australia to describe fracture incidence and fracture trends in children or adolescents. The only published works of an Australian population thus far, reported fracture incidence in the city of Geelong, Victoria. This study reported fracture incidence for individuals aged 35 years and above (an adult population), and showed that as people age the fracture incidence for women increases at a greater rate than men [16]. When urban and rural fracture incidence was compared in this cohort, it was found that individuals who live in an urban environment have a significantly greater fracture incidence per 10^4 than those who live in a rural environment (99 and 89 respectively; $p \leq 0.01$) [17]. However, as noted, this singular piece of work focused on adults, with no known published data in paediatric populations of Australia.

Western Australia is a state with unique geography and population distribution having only a single tertiary paediatric hospital (Princess Margaret Hospital, PMH, in Perth) managing the majority of children and adolescents from birth until 16 years of age with fractures in the Emergency Department

(ED). The aim of this study was to (1) characterise fracture presentations to the PMH Emergency Department (ED) and (2) compare the fracture incidence to population data.

METHODS

Study Design

This was a retrospective review of de-identified presentations to the emergency department in patients who were diagnosed with a fracture expressed relative to population data. Patient data was captured using the Emergency Department Information System (EDIS; HAS Solutions Pty Ltd, Version 9.46.1001 ER15 2010). Search of EDIS using ICD:10 codes was used to identify the presentations with fractures (ICD S42.2, S42.3, S42.4, S52.0, S52.2, S52.3, S52.4, S52.5, S62.2, S62.5, S62.6, S72.0, S72.1, S72.3, S72.4, S82.1, S82.18, S82.2, S82.28, S82.5, S82.6, S82.81, S82.82, S82.88, S92.2; further details, see Supplementary Table 1). Ethics approval was obtained from the PMH Human Research Ethics Committee (GEKO ID: 12649) for analysis and subsequent publication of the de-identified data.

Outcome Parameters

Audit variables included date of emergency department presentation, age in years, fracture site and gender (male or female). Fracture incidence was recorded monthly. Age was categorized as a whole number. Ages were rounded down from .49 and up from .5. Fracture site was categorised as being either an upper limb fracture (including finger fractures) or a lower limb fracture (including toe fractures). Finger and toe fractures were not excluded from analysis as per protocols of previously reported studies (Tiderius, Landin, & Düppe, 1999; Ramaesh, Clement, Rennie, Court-Brown, & Gaston, 2015; Rennie, Court-Brown, Mok, & Beattie, 2007; Mäyränpää, Mäkitie, & Kallio, 2010). Other fracture sites were not included in this analysis. Fracture confirmation was conducted using a random sample of 203 upper limb fracture cases. This random sample of 203 was chosen based on if the true prevalence of the misdiagnosis of fractures was 5% [18], with a 95% confidence interval, and if the level of precision is within 3% of the true population prevalence. From the 203 cases, 184 cases were confirmed by x-ray to be fractures, with 16 of the non-confirmed fractures confirmed by x-ray. Therefore 98.5% of positive fracture assessments at presentation for the upper limb were confirmed as having a fracture. Based on clinical expert opinion a similar rate was anticipated for lower limb fractures.

Western Australian (WA) population data and estimated age-related population numbers for the Perth Metropolitan area were extracted from the Australian Bureau of Statistics [19] by the Epidemiology Branch of WA Department of Health. Population data was given in year ranges; 0-4, 5-9, 10-14, and

15-19 years. Using Beers' method [20], yearly individual age ranges were estimated from the five-year brackets.

Statistical Analysis

Statistical analyses were conducted with SPSS Version 19.0.0 (IBM Corporation, Somers, NY, USA) with significance set at $p < 0.05$. Variables analysed included the fracture incidence (count), month, year, gender, fracture site (upper or lower limb), age group (year groups 0 – 16) and matching Perth Metropolitan population statistics. However, due to population statistic availability, population representation in Figure 5b* is delimited to 0-15. Variables were described using frequency and percentage. A negative binomial with log link Generalized Linear Model (GLM) was performed to determine trends over time, with group differences examined using Bonferroni corrected pairwise comparisons.

The GLM was performed with the fracture count as the outcome. Fracture site, age group and month were treated as factors, and year treated as a covariate. The natural logarithm of the population was included as an 'offset variable' to correct for the different levels of exposure to fracture based on population size. Three models were investigated: Model 1 examined all of the above variables with an interaction added between year and fracture site. Model 2 and Model 3 included the above variables, separately for each fracture site (i.e. data was split for fracture site and hence fracture site removed as a factor) in order to investigate the individual contribution (rate of change) of each fracture site (upper arm fracture and lower arm fracture). Analyses were conducted with a 95% confidence interval (CI), with odds ratio (OR) and CI presented.

Model 1 can be described by the following equation:

$$Fractures = intercept + (Age\ Group\ \beta) + (Gender\ Group\ \beta) + (Month\ Group\ \beta) + (Fracture\ site\ \beta) + (Year\ \beta \times year).$$

Model 2 (upper fracture site) can be described by the following equation:

$$Fractures = intercept + (Age\ Group\ \beta) + (Gender\ Group\ \beta) + (Month\ Group\ \beta) + (Year\ \beta \times year).$$

Model 3 (lower fracture site) can be described by the following equation:

$$Fractures = intercept + (Age\ Group\ \beta) + (Gender\ Group\ \beta) + (Month\ Group\ \beta) + (Year\ \beta \times year).$$

RESULT

Participants

A total of 31,340 out of 681,134 emergency department presentations were to rule out fractures. According to our validation, 98.5% can be considered positive. Total fractures for this study were 31,340 which included 27,516 individual children (87.8%) comprising 24,480 children reporting one fracture (78.1%), and 3,036 children reporting two or more fractures (9.7%). Males had a 1.5 times higher fracture incidence than females ($p < 0.001$).

Fracture Incidence

The yearly reported fracture rate was the lowest in 2005 with 2040 fractures, and the highest in 2014 with 3711 fractures, with a slight decrease in 2015 to 3532 fractures (Figure 1a). During this period, the percentage of presentations for a suspected fracture increased from 4.43% (2005) to 5.44% (2015). The absolute fracture incidence per 10^4 people increased from 63 in 2005 to 85 in 2015 (Figure 1b). In relation to the estimated population number in the Perth metropolitan area, this equals 0.64% in 2005, 0.92% in 2014, and 0.85% in 2015 (Supplementary Table 2). In relation to the total population of Western Australia this represents 0.47% in 2005 and 0.67% in 2015. GLM Model 1 (Supplementary Table 3) confirms that there is a statistically significant 5.0% increase in rate of fractures each year ($p < 0.001$). When fracture site is examined separately using GLM Models 2 and 3 (Supplementary Tables 4 and 5) we found that arm fracture rates significantly increase, but at a slower rate per year (4.0%, $p < 0.001$) compared to leg fractures (5.3%, $p < 0.001$) (Figure 1c).

[Insert Figure 1 approximately here]

Monthly Fracture Incidence

Over the audit period, the monthly fracture incidence fluctuated across the year, with lowest in January, July and December, and highest in May with 3325 fractures (Figure 2a). Seasonal differences in fracture incidence remained significant when controlling for population growth, gender and year with May presenting a 1.4 times higher risk of a child receiving a fracture ($p < 0.001$). This trend was similar when comparing upper and lower limb fracture sites across months (Figure 2b). When fracture site was examined separately, the month of May continued to present the highest risk period for both an arm fracture with a 1.5 times higher risk of a child receiving a fracture, $p < 0.001$ (GLM Model 2), and leg fracture with a 1.4 times higher risk of a child suffering a fracture, $p < 0.001$ (GLM Model 3). In contrast, there was some level of risk across each month for a leg fracture, while for arm, the month of January and July did not increase the risk of fracture (OR = 0.9, 95% CI 0.8-1.0 $p = 0.150$ and OR = 0.9, 95% CI 0.8-1.2 $p = 0.818$ respectively).

[Insert Figure 2 approximately here]

Fracture Site Incidence

There were almost three times more upper limb fractures than lower limb fractures (23,385 versus 7,955) across the study period. This proportionality was consistent for both males and females (Figure 3a) and confirmed when controlling for other factors (GLM Model 1, OR = 2.9, 95% CI 2.7 – 3.0 $p < 0.001$). When fractures were examined separately for upper and lower limb sites, upper limb fractures were dominant and followed a similar trend to overall fracture incidence for age with a peak at 12 years (Figure 3b). For the upper limb (GLM Model 2), the fracture incidence was similar to the overall model with significantly lower fracture incidences for 0, 1 and 16 years, and significantly higher fracture incidences for 11, 12 and 13 years. Age groups 11, 12, and 13 years were also at the highest risk of an upper limb fracture (4.5, 4.7, and 4.5 times more likely respectively, $p < 0.001$), while infants (age group 0) were unlikely to fracture.

[Insert Figure 3 approximately here]

Gender Differences in Fracture Incidence

Over the study audit period (2005-2015) males (18,763) had a higher fracture incidence than females (12,577) ($t = 4.589$, $p < 0.001$) for all age groups except 1 year (Figure 4a). This difference was sustained across audit years with fracture incidence increasing for both males and females (Figure 4b), as well as between fracture sites (Figure 3a). However, the trend over time differed. Fracture incidence continued to increase for males until a peak at 14 years, while female's fracture incidence peaked earlier at 11 years. GLM Model 1 confirmed a difference between gender with males 1.5 times more likely to incur a fracture compared to females ($p < 0.001$). Specifically, males were 1.5 times more likely to have an upper arm fracture ($p < 0.001$ GLM Model 2) and 1.5 times more likely to incur a lower leg fracture ($p < 0.001$ GLM Model 3) than females.

[Insert Figure 4 approximately here]

Fracture Incidence across Age Groups

The fracture incidence increased gradually from infancy, peaking at 12 years with 2,840 fractures then decreasing to 690 fractures at 16 years (Figure 5a). The GLM Model 1 showed the low fracture incidence for 0, 1 and 16 years was significantly lower ($p < 0.05$) from the other age groups, while the high fracture incidence for 12, 13 and 14 years was significantly higher than 0-8, 9 (only for 12 years), 15 and 16 years ($p < 0.005$). Children aged 12, 13 and 14 years had the highest risk of fracture, (4.2, 4.0 and 4.0 times more likely respectively, $p < 0.001$), while infants were unlikely to fracture. The fracture incidence per 10^4 people was lowest for 0 years (4) and highest for 12 years (115) (Figure 5b). As previously noted, data for the 16 year age group was not presented (Figure 5b) due to the availability of Perth Metropolitan population data for those aged 16.

Lower limb fractures showed a different trend to upper limb fractures (Figure 3b). The lowest number of lower limb fractures occurred in infancy with 53, and a peak number of lower limb fractures occurred at two years with 802 decreasing to a rebound at five years, returning to a second peak at 14 years, before decreasing again to 16 years. For the lower limb (GLM Model 3), the fracture incidence for 0 and 16 years was significantly lower than all other age groups ($p < 0.05$). Children in age groups 2, 11, 12, 13 and 14 years were at the highest risk of lower limb fracture (3.1, 3.4, 3.6, 3.5, and 3.8 times more likely respectively, $p < 0.001$), while infants were unlikely to fracture.

[Insert Figure 5 approximately here]

Discussion

Relative to population growth, we found fracture incidence in children is increasing in Perth, Western Australia, and that upper appendicular fracture incidence is increasing at a faster rate to lower appendicular fracture incidence. While there is a drop off in the fracture incidence from 2014 to 2015, this may be due to the fracture incidence in 2013 and 2014 peaking far above the usual yearly increase in fracture incidence. The fracture incidence in 2015 represents the natural trend of the years prior to 2013. Although our study dates are later than previously reported studies in Table 1, our incidence rates, although increasing, remain relatively low compared to other countries. Our results are most closely aligned with the United Kingdom [5].

[Insert Table 1 approximately here]

The current research focused upon the characterisation and comparison of fracture incidence in children and adolescents in Western Australia. Although analysing mechanisms of injury and fracture incidence is critical for a greater understanding of contributing factors to fractures in children and adolescents, evaluating incidence and mechanism of injury was considered beyond the scope of the current paper and purpose.

Compared to some European countries such as those with a latitude greater than 40 degrees North (including Austria, Germany, Sweden, the United Kingdom) where sunlight is not sufficient to trigger vitamin D synthesis all year round [28], Western Australia has an abundance of sunlight. Data for sun-exposure were not available for this study, it cannot be assessed whether lower fracture rates in Western Australian youth may be attributed to this. Studies show that vitamin D deficiency is present in WA but detailed data are only available for risk groups (Wadia et al., 2018). Another potential factor is that the fracture presentation rate to PMH-ED is not 100%. Some patients might have been seen at other hospitals, by their general practitioner, or remained untreated. Similar to other studies, the overall fracture incidence in our study is increasing [6,7,10]. Possible explanations as suggested in the literature include changes in daily physical activity levels [29], increased prevalence of overweight and obese children [30], gender [5,26,27], and differences in the month or time of year of presentation[6,26].

Physical activity data was not available for this audit study, however physical activity has been shown to be a factor in fracture incidence [33]. During this study period physical activity behaviours in Australia have changed from transport-related (i.e. cycling or walking between locations) to recreational [31]. Recreational activities have been shown by others to report higher incidence of fractures compared to transport-related physical activities [34]. Therefore it is possible that the increases reported in this cohort may be related to the change in physical activities undertaken by children and adolescents. Furthermore, while obesity has been implicated in increased fracture incidence due to falls [30], we speculate that this is unlikely to account for the increase in fracture incidence seen in the current study because the prevalence of overweight and obesity in Western Australia has remained relatively unchanged over the study period [37]. It should be noted that BMI data was not available for this study.

In keeping with other studies [5-7,10] males had a 1.5 fold higher incidence of both upper and lower limb fractures. Males participate in more contact sports than females, and hence are at higher risk of fracture. Children have been participating in organised sport from as early as five years old, with 60% of 5 to 14 year olds participating in organised sport, with 9-11 year olds having the highest participation rates (66%) compared to 5-6 year olds (56%) and 12-14 year olds (60%) [38]. In Western Australia the participation rates were higher for boys (72%) compared to girls (54%) [38]. The most popular organised sports (including dancing) for boys aged 5 to 14 in Australia from the end of April in 2011 to the end of April in 2012 were soccer (21.7%), swimming/diving (16.5%) and Australian Rules Football (14.9%), while for girls aged 5 to 14 it was dancing (27.1%), swimming/diving (18.9%) and netball (16.2%) [38]. Fracture incidence for males follows the trend of increasing until

14 years of age and then decreasing, whereas fracture incidence for females follows the same trend until the age of 11 before decreasing (Figure 4a). This may be because females tend to stop playing sports at an earlier age than males, and girls participate in less sport than boys from as early as the ages of 1 to 3 years [39]. Given bone formation is similar for either sex until after the end of longitudinal growth, and people are most susceptible to fractures during adolescence [40], the decrease in physical activity by females may be the most likely explanation for lower fracture rates when compared to males. Differences in fracture incidence between males and females could also be due to the peak height velocities during puberty, which occurs for boys at an average age of 13.5 years old but earlier for girls at an average age of 11.5 years [12,13]. The ages during which peak height velocities occur (during puberty) are associated with an increased fracture incidence [41]. There is an increased fracture risk during this time possibly due to the decrease in bone mass relative to the vertical growth height of the individual [41]. After the age of 15 years, fracture incidence decline may be due to a change in leisure time activity with less focus on organized sport [42]. Specific to this study, another reason for the low fracture rates for children of 16 years may be that Princess Margaret Hospital only treats people aged 16 years and older in exceptional circumstances.

The summer months of December, January and February had the lowest fracture incidence other than July (Figure 2a). This may be related to the sports children play during this season. The national sport during the Australian summer is cricket, which is a non-contact sport [43], whereas the most popular sport during the Australian winter is Australian Rules Football, which is a contact sport [44,45]. Contact sports have a greater chance of causing fractures than non-contact sports, which may account for the lower fracture incidence in the summer months. May has the highest fracture incidence, and this is likely due to contact sports, such as Australian Rules Football, beginning their junior seasons during May or late April. These seasonal differences are confounded by the Australian school holiday periods which occur during April, July, September/October, and December/January. Organised sport tends to operate during school terms with sporting breaks to coincide with the respective holiday periods. Results of this study vary from results of countries in the Northern Hemisphere. While a higher fracture incidence when performing winter sports in children and adolescents is also shown in Finland [26], there are studies from Wales [8] and Scotland [25] which have shown the fracture incidence to be the highest during the summer months.

This study was limited as an audit to the only tertiary children's hospital in Western Australia that is based in the Perth metropolitan area and therefore only included emergency presentations to this hospital. It is likely that fracture presentations of children could have been made to other hospitals or local doctor's surgeries. Therefore, incidence rates reported are plausibly underestimated. Our validation resulted in a lower percentage of missed fractures than previously reported in the literature [6]. It should be noted that 11.9% of fractures reported in this audit represented multiple fractures.

CONCLUSION

Fracture incidence and mechanisms are multi-factorial and evolve as children age, particularly in response to changes in physical development, maturation and lifestyle behaviours. However, the increased incidence in Western Australia between 2005 and 2015 identifies a concerning trend for bone health in children and adolescents that needs addressing. Further research is needed to identify potential lifestyle factors that impact fracture incidence in order to reverse the stifle and reverse fracture incidence trends seen in children and adolescents in Western Australia.

DISCLOSURE STATEMENT

Mr Mark Jenkins drafted the initial manuscript. Mr Mark Jenkins, Dr Sophia Nimphius, Dr Nicolas H. Hart, Dr Paola Chivers, Dr Timo Rantalainen, Dr Fleur McIntyre and Dr Aris Siafarikas conceptualized the research design and interpreted results. Mr Mark Jenkins and Dr Paola Chivers analyzed, and Dr Sophia Nimphius and Dr Nicolas H. Hart reviewed statistical methods. Dr Kristina Rueter, Dr Meredith L. Borland, Dr Katherine Stannage and Dr Aris Siafarikas contributed to data acquisition and interpretation. All authors critically evaluated and approved the final draft. Mr Mark Jenkins, Dr Sophia Nimphius, Dr Nicolas H. Hart, Dr Paola Chivers, Dr Timo Rantalainen, Dr Kristina Rueter, Dr Meredith L. Borland, Dr Fleur McIntyre, Dr Katherine Stannage and Dr Aris Siafarikas declare that they have no conflicts of interest.

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Figure Titles

Figure 1. Fractures incidence (A) total per year, (B) per 10^4 persons per year, and (C) total split into upper and lower limb fractures from 2005 to 2015.

Figure 2. Fracture incidence (A) each month and (B) each month split into upper and lower limb fractures from 2005 to 2015.

Figure 3. Fracture incidence in upper and lower limb (A) as a total in males and females over 2005 to 2015 and (B) at each age from 2005 to 2015.

Figure 4. Fracture incidence total for males and females (A) at each age and (B) over 2005 to 2015.

Figure 5. Fracture incidence (A) total by age and (B) per 10^4 persons from 2005 to 2015.

Table Titles

Table 1. Summary table of studies describing fractures in children [2-10,21-27].

Supplementary Files

Supplementary Table 1. Detailed description of ICD10 codes used for database query

Supplementary Table 2**.** Yearly fracture incidence, population, and fracture incidence per 10^4 people.

Supplementary Table 3. GLM Model 1 Parameter Estimates for when site is used as a factor.

Supplementary Table 4. GLM Model 2 Parameter Estimates for upper limb sites only.

Supplementary Table 5. GLM Model 3 Parameter Estimates for lower limb sites only.