METHODOLOGIC ISSUES

Out on a limb: risk factors for arm fracture in playground equipment falls

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Objectives: To investigate and quantify fall height, surface depth, and surface impact attenuation as risk factors for arm fracture in children who fall from playground equipment.
Design: Unmatched case control study.
Setting: Five case hospitals and 78 randomly selected control schools.
Participants: Children aged less than 13 years in Victoria, Australia who fell from school playground equipment and landed on their arm. Cases sustained an upper limb fracture and controls had minor or no injury. A total of 402 cases and 283 controls were included.
Interventions: Children were interviewed in the playground as soon as possible after their fall.
Main outcome measures: Falls were recreated on site using two validated impact test devices: a headform (measuring peak G and HIC) and a novel anthropometric arm load dummy. Equipment and fall heights, as well as surface depth and substrate were measured.
Results: Arm fracture risk was greatest for critical equipment heights above 1.5 m (OR 2.39, 95% CI 1.49 to 3.84, $p<0.01$), and critical fall heights above 1.0 m (OR 2.96, 95% CI 1.71 to 5.15, $p<0.01$). Peak headform deceleration below 100G was protective (OR 0.67, 95% CI 0.45 to 0.99, $p=0.04$). Compliance with 20 cm surface depth recommendation was poor for both cases and controls.
Conclusions: Arm fracture-specific criteria should be considered for future standards. These include surface and height conditions where critical headform deceleration is less than 100G. Consideration should also be given to reducing maximum equipment height to 1.5 m. Improved surface depth compliance and, in particular, guidelines for surface maintenance are required.

Play is essential to child development; however playgrounds can also pose serious safety risks. Where contributing factors are known, falls from playground equipment are the leading cause of all child fall related hospitalization in Australia.[1] Upper limb fracture is the most common playground injury, accounting for 43% of emergency department presentations and 74% of hospital admissions.[2 3] Playground injury is moderately severe, with 22% of children presenting to emergency departments and 32% of those with arm fracture requiring hospitalization.[2]

Current playground safety standards adopt a headform impact test, with peak deceleration below 200G and head injury criteria (HIC) below 1000, as a guide for determining safe equipment height and surface depth.[4–7]

Previous analytical research has identified the height of playground equipment from which the child falls[8 9] and impact attenuation[10] as risk factors for injury. Playground injury risk was 2.3–4.1 times greater for falls from equipment heights above 1.5 m compared with falls from equipment 1.5 m and below,[8 9] and 3.0 times greater for impact above 200G compared with below 150G.[10]

No studies to date have addressed specific risk factors for playground fall related arm fracture. Although recovery from arm fracture is generally complete, high exposure to playgrounds, high incidence of arm fracture, burden on the healthcare system, and promising countermeasures, make playground arm fracture prevention a priority.

AIM

To investigate and quantify fall height, surface depth, and surface impact attenuation as risk factors for arm fracture in children who fall from playground equipment.

METHODS

This is an unmatched case control study adhering to national ethical guidelines.[11] The detailed methods have been described previously.[12] The study base was children aged less than 13 years in Victoria, Australia who fell from school playground equipment and landed on their arm. Cases sustained an ICD-10-AM coded[13] upper limb fracture. Controls had minor or no injury and were recruited from 78 primary and preschools randomly selected from within the catchment area of the five participating case hospitals.

Children were interviewed at the fall site and asked the following:

- From which piece of equipment did you fall?
- What were you doing just before you fell?
- Where did you land?

Adult eyewitnesses, where available, validated the child's account of the fall. School administrators self-reported any modifications to the playground equipment or the playground surface following the child's fall. Where modifications occurred, children were interviewed and child characteristics measured, but playground measurements were excluded.

Surface depth was the average of three probe readings taken 30 cm apart in a triangle at the reported point of

Abbreviations: CoG, centre of gravity; HIC, head injury criterion; HIC_{1m}, HIC from 1 m drop height; HIC_{CoG}, HIC from child fall height; $HIC_{equipment}$, HIC from maximum equipment height; G_{1m}, peak headform deceleration from 1 m drop height; G_{CoG}, peak headform deceleration from child fall height; $G_{equipment}$, peak headform deceleration from maximum equipment height.

arm-surface contact.[5] Surface substrate was determined by digging into the surface with a small shovel and identifying the material beneath the surface.

Equipment height was the vertical distance from the surface to the highest accessible part of the structure.[14] Child fall height was the vertical distance between the surface and the child's centre of gravity (CoG) at the start of their fall. CoG tables were based on child anthropometric data,[15 16] adapted for common play positions.

Falls were recreated on site using two validated impact test devices: an instrumented headform and a novel anthropometric child arm load dummy.[12] Each device was dropped three times from the fall height. The headform was additionally dropped from the equipment height[5] and from a standard 1 m drop height. HIC was determined using the deceleration time trace.[5] The greatest peak headform deceleration (G_{1m}, G_{CoG}, $G_{equipment}$), HIC (HIC_{1m}, HIC_{CoG}, $HIC_{equipment}$), and arm load for each drop height was used in subsequent analyses.

Student *t* and χ^2 tests ascertained case and control similarities. Multivariate logistic regression described the relation between the fall outcome (fracture, no fracture) and multiple playground variables, while controlling for confounding variables. All analyses were conducted using SPSS software for a personal computer (version 11, SPSS Inc, Chicago, IL, USA).

RESULTS

Data were collected between October 2000 and December 2002. Participating hospitals identified 660 potential cases and 420 (63.6%) were interviewed. Reasons for non-participation included: school declined participation (3.1%); family declined participation (4.2%); and family not contactable after five telephone attempts (29.0%). Upon medical record review, 18 further cases were excluded for non-confirmed fracture.

A total of 402 cases and 283 controls were included. Cases and controls did not differ significantly (table 1), with the exception of child height, which was subsequently controlled for in multivariate analyses. Children were interviewed and playgrounds measured within 20.5 (SD 10.4) days (cases) and 12.5 (SD 10.0) days (controls) of their fall. A parallel study indicated that there was no significant difference between children (cases and controls) and adult eyewitnesses in describing the playground fall, including confirmation that the child landed on their arm.[17]

The playground surface was modified following the child's fall in 32 case playgrounds (7.7%) and three control playgrounds (1.1%) and these playground measurements were excluded. Results indicated that cases fell from significantly greater equipment and fall heights, resulting in significantly greater peak impact deceleration (G_{CoG}) and HIC (HIC_{CoG}) when compared with controls. Bivariate analysis showed that mean arm loads were not significantly greater in recreated playground falls for cases (5.30 kN) and controls (5.23 kN) (table 2) and this was confirmed in the multivariate analysis (table 3).

Multivariate logistic regression analysis (table 3) indicated that children who fell from equipment heights greater than 1.5 m were 2.4 times more likely to sustain an arm fracture compared with children who fell from equipment 1.5 m or less ($p<0.01$). In addition, children who fell more than 1.0 m were 3.0 times more likely to sustain an arm fracture compared with children who fell less than or equal to 1.0 m ($p<0.01$).

Headform peak deceleration of 100G and above represented an arm fracture risk approximately 1.5 times that of less than 100G for tests conducted from fall height (G_{CoG}) ($p = 0.02$) and from equipment height ($G_{equipment}$) ($p = 0.04$) (table 3).

There was no significant difference between cases and controls in terms of surface material type or depth. However sand substrate was protective when compared with soil ($p<0.01$) (table 3).

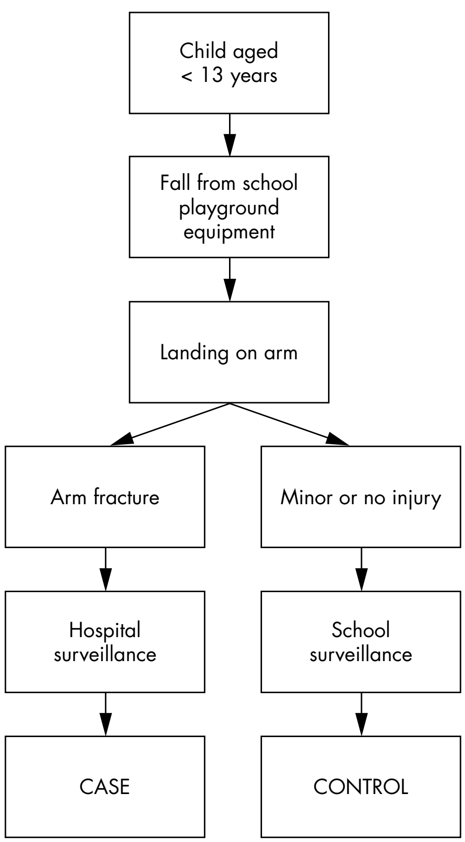

Figure 1 Case control study design (reprinted from the authors' earlier paper[12]).

DISCUSSION

Equipment and fall heights are key risk factors for arm fracture in children who fall from playground equipment. Arm fracture risk was significantly greater for equipment heights exceeding 1.5 m and fall heights greater than 1.0 m. Previous recommendations include limiting maximum equipment height to 1.5 m[8 9] or 2.0 m.[10] Most cases in these previous studies (76–82%) sustained arm injuries, which may explain their similar findings to the current study—providing compelling evidence that falling from equipment heights greater than 1.5 m significantly increases children's risk of arm fracture.

Table 1 Description of cases and controls

	Cases n=402 (%)	Controls n=283 (%)	Test statistic
Female	227 (56)	164 (58)	
Male	175 (44)	119 (42)	$\chi^2=0.15$, p=0.70
Mean age (years)	7.13	7.36	*t*=1.63, p=0.10
Child height (mm)	1280	1299	*t*=2.15, p=0.03*
Child weight (kg)	28.0	29.0	*t*=1.65, p=0.10
Body mass index (kg/m^2)	16.8	16.9	*t*=0.67, p=0.51

*p<0.05.

Table 2 Case and control playground measurements

Measurement	Cases n	Cases Mean	Cases SD	Controls n	Controls Mean	Controls SD	Test statistic
Equipment height (m)	371	2.04	0.43	279	1.97	0.52	$t=1.96$, $p=0.05$*
Fall height (m)	371	1.52	0.37	279	1.42	0.41	$t=3.10$, $p<0.01$*
Surface depth (mm)	361	111	50	271	104	51	$t=1.73$, $p=0.08$
Arm load (kN)	369	5.30	1.91	276	5.23	1.68	$t=0.47$, $p=0.64$
G_{1m}	339	82.87	38.83	265	78.76	27.19	$t=1.47$, $p=0.14$
G_{CoG}	276	102.29	43.96	260	94.38	37.43	$t=2.24$, $p=0.03$*
$G_{equipment}$	198	118.45	46.42	229	111.98	42.56	$t=1.50$, $p=0.13$
HIC_{1m}	339	241.23	185.55	265	230.02	161.00	$t=0.78$, $p=0.44$
HIC_{CoG}	276	439.43	398.70	260	371.08	265.62	$t=2.31$, $p=0.02$*
$HIC_{equipment}$	198	615.04	450.75	229	553.95	365.61	$t=1.54$, $p=0.13$

*$p \leqslant 0.05$.

As illustrated in table 3, arm fracture risk was significantly greater for falls from equipment heights of 1.5–1.9 m. The greatest risk reduction was for critical equipment height below 1.5 m. Further research is necessary to determine a balance between positive play experiences and reducing equipment height.

Arm fracture risk was significantly higher when peak deceleration exceeded 100G, which supports previous research where the incidence of general playground injury was associated with peak deceleration greater than 150G.[10]

No significant difference was detected between case and control playground surface depths. The proportion of

Table 3 Risk factors for arm fracture in falls from playground equipment

Variable	Categories	Crude OR	Crude 95% CI	Crude p Value	Adjusted OR*	Adjusted 95% CI	Adjusted p Value
Equipment height (narrow)	⩽1500 mm	–			–		
	1501–2000 mm	2.52	1.51–4.21	0.00†	2.53	1.51–4.24	0.00†
	2001–2500 mm	2.33	1.41–3.83	0.00†	2.47	1.49–4.10	0.00†
	>2500 mm	1.55	0.80–3.00	0.20	1.66	0.85–3.25	0.14
Equipment height (broad)	1.5 m and below	–			–		
	>1.5 m	2.29	1.43–3.66	0.00†	2.39	1.49–3.84	0.00†
	1.6 m and below	–			–		
	>1.6 m	2.03	1.33–3.09	0.00†	2.06	1.35–3.15	0.00†
	1.7 m and below	–			–		
	>1.7 m	1.70	1.16–2.50	0.01†	1.74	1.18–2.56	0.01†
	1.8 m and below	–			–		
	>1.8 m	1.79	1.27–2.54	0.00†	1.87	1.32–2.66	0.00†
	1.9 m and below	–			–		
	>1.9 m	1.34	0.97–1.85	0.08	1.41	1.01–1.96	0.04†
	2.0 m and below	–			–		
	>2.0 m	1.10	0.81–1.51	0.53	1.17	0.85–1.61	0.33
Fall height (narrow)	⩽1000 mm	–			–		
	100–1500 mm	2.60	1.48–4.55	0.00†	2.73	1.55–4.82	0.00†
	1501–2000 mm	3.13	1.72–5.70	0.00†	3.53	1.92–6.50	0.00†
	greater than 2000 mm	2.44	1.20–4.96	0.01†	2.94	1.42–6.09	0.00†
Fall height (broad)	⩽1000 mm	–			–		
	>1000 mm	2.73	1.59–4.71	0.00†	2.96	1.71–5.15	0.00†
Surface type	Tanbark, rubber, sand	–			–		
	Non-compliant material	1.42	0.42–4.75	0.57	1.37	0.41–4.61	0.62
Surface depth	⩾20 cm	–			–		
	15–19.9 cm	1.48	0.66–3.32	0.34	1.52	0.68–3.44	0.31
	10–14.9 cm	1.13	0.53–2.42	0.75	1.12	0.52–2.42	0.77
	5–9.9 cm	1.11	0.52–2.36	0.79	1.10	0.52–2.36	0.80
	<5 cm	0.66	0.28–1.53	0.33	0.62	0.26–1.46	0.28
Substrate material	Soil	–			–		
	Sand	0.29	0.16–0.53	0.00†	0.29	0.16–0.53	0.00†
	Other	1.27	0.43–3.77	0.66	1.26	0.43–3.76	0.67
Arm load (kN)		1.02	0.94–1.11	0.64	1.03	0.95–1.13	0.47
$G_{equipment}$	⩾200G	–			–		
	<200G	0.52	0.21–1.27	0.15	0.53	0.22–1.32	0.17
$G_{equipment}$	⩾100G	–			–		
	<100G	0.65	0.44–0.96	0.03†	0.67	0.45–0.99	0.04†
G_{CoG}	⩾100G	–			–		
	<100G	0.65	0.46–0.93	0.02†	0.65	0.46–0.92	0.02†
$HIC_{equipment}$	⩾1000	–			–		
	<1000	0.78	0.43–1.39	0.39	0.78	0.44–1.40	0.41

*Adjusted for child height.
†$p<0.05$.

compliant playgrounds was much poorer than anticipated from pilot studies and the study sample was highly skewed towards non-compliant depth. Post hoc analysis indicated only 54% power to detect an odds ratio of two at 95% confidence. Thus, surface depth results were underpowered and inconclusive. Limited statistical power has also disadvantaged previous studies, including 100% surface depth non-compliance.[8 9]

Although surface depth is a significant factor in the impact attenuation of loose fill surfacing under laboratory conditions,[18–21] no study has yet linked poor surface depth to an increased risk of injury in situ. These results strongly indicate that laboratory based studies of surface depth do not translate well to surface performance in situ. This is further supported by recent research, where for similar surface depths, impact deceleration was lower in situ than under laboratory conditions.[22]

Surface substrate was the most significant surface related risk factor for arm fracture. The risk of arm fracture was significantly lower when falling onto tanbark surfacing installed over sand compared with soil substrate. Sand substrate may contribute to increasing impact attenuation by decreasing surface stiffness, a known contributor to reducing impact forces in falls onto the outstretched arm.[23] Sand may also improve the surface drainage, thus potentially decreasing the rate of degradation of organic surface material such as tanbark. Substrate findings support the need to test surface impact in situ and not to rely solely on interpreted laboratory based surface safety measures.

This study improves on previous study designs by applying multidisciplinary methods to identify risk factors for playground fall related arm fracture and quantifying physical measures related to injury risk. Novel instrumentation was developed and, for the first time, real-world playground falls were recreated to quantify case and control arm loads. Validated biomechanical instruments were combined with rigorous epidemiological methods,[12] thus producing representative and robust results. Fall height measurements were distinct from equipment height and based on the child's CoG.

Strengths of the study include the large sample size, representative control group, and a standard protocol under which the study was conducted. Children (rather than a proxy) were interviewed directly to identify the playground equipment involved. Field tests were conducted as soon as possible to minimise any playground changes and maximize child recall. In a parallel study, child falls were validated by adult eyewitnesses, and agreement averaged 76–90%, which was significantly better than chance for child recall ($p<0.01$).[17]

Although conducted in school playgrounds, impact results could be generalised to all playgrounds with tanbark surfacing. In particular, study cases did not differ significantly from all children presenting to Victorian hospitals for playground fall related arm fracture during the study period by age ($p = 0.07$) or sex ($p = 0.10$).

The arm loads measured in situ (table 2) were higher than the 4.20 kN impact loads predicted mathematically for 2.0 m falls onto the outstretched hand.[25] Although cases and controls were subjected to comparable arm impact loads, controls appeared better able to accommodate these loads safely, possibly by landing in a way that attenuated the impact forces. Active fall arrest strategies, such as bending the elbows and minimising the impact velocity of the hand relative to the surface, have been proven to reduce upper limb impact forces in young adult subjects.[25]

The arm load dummy was a first attempt to model a biofidelic child arm for fall impact testing. The model did not account for variable stiffness, nor for damping of the joints and segments of the arm, which are important components of fall impact attenuation.[24 25] A more biofidelic model is required to provide greater measurement capacity, and to differentiate the subtleties in the biomechanics of child falls onto outstretched arms. Arm fracture criteria should be further developed and included in playground standards to complement HIC as a critical guide to playground safety. These results indicate that there is a 90% probability of arm fracture when arm loads exceed 3.0 kN. A preliminary arm fracture criteria is thus proposed such that impact arm loads should not exceed 3.0 kN.

Theoretically, a number of different fall height and surface depth combinations could produce 100G or less impact forces. Based on the results of almost 700 real-world playground falls, we found that 100G headform impact deceleration corresponded to approximately 1.0 m fall height onto 16 cm depth of tanbark surface. Real-world fall height and surface depth are provided as a guide only and are not intended to replace in situ impact testing to assess playground injury risk.

CONCLUSIONS

Arm fractures from falls from playground equipment remain the most frequent, significant, and preventable injury in this setting.

Consideration should be given to reducing maximum equipment height. The current allowable height in Australia of 2.5 m carries significant risk of arm fracture. Reducing maximum equipment height to 1.5 m, such that children cannot get their centre of gravity more than 1.0 m off the ground, can attain the greatest reduction in arm fracture risk. However gains can be made with equipment height reductions to at least 1.9 m (table 3). Steps should also be taken to prevent falls from higher equipment by installing guard rails.

Arm fracture-specific safety criteria should be considered for future standards. Specifically, surface and height conditions should be adopted where critical headform deceleration from the equipment height does not exceed 100G.

Surface substrate was the most significant surface related risk factor for arm fracture, with sand providing a protective effect. Maintenance of surface depth is also an important consideration. If surface depth were maintained at 20 cm, impact deceleration would not exceed the 100G limit for fall heights of 1.0 m. In addition, a significant number of playgrounds measured (36% cases and 46% controls) currently yield impact test readings below 100G (from equipment height), indicating a good base from which to improve.

Although adopting these recommendations may require going out on a limb, they are critical for preventing a common, traumatic, and costly childhood injury.

Key points

- Previous analytic studies have identified equipment height as a risk factor for fall related playground injury.
- No studies to date have identified specific risk factors for playground fall related arm fracture, despite their common and costly occurrence.
- This case control study suggests that fall height above 1.0 m, equipment height above 1.5 m, and headform peak deceleration above 100G are significant risk factors for playground fall related arm fracture.
- Future playground standards should be reviewed to include arm fracture-specific countermeasures.

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