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Engineering Safety in Childhood Bone Fragility: Built Environments for Fracture Prevention

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Childhood bone fragility conditions affecting balance and coordination share a common feature: fractures often follow minor impacts in ordinary spaces.[1] In these disorders, risk is shaped not only by bone biology, but also by modifiable features of the built environment.[2] Designing environments that reduce these impact hazards for children with bone fragility ultimately makes everyday spaces safer and more accessible for everyone. This issue is exemplified in Osteogenesis imperfecta (OI), a heritable connective tissue disorder characterized by bone fragility and fractures after minimal trauma. OI is often accompanied by skeletal deformity that threatens mobility.[1] Almost half of children and one-third of adults with OI experience a fracture within one year of diagnosis.[2] Fracture risk in pediatric OI is informed by exposure to environmental hazards, with the built environment directly influencing injury frequency and severity. OI, therefore, requires lifelong hazard circumvention, which often leads to exhaustion and isolation.[3]

Current OI management combines medical and rehabilitative interventions, including bone-active therapy and corrective surgery.[4] This approach treats OI-related disability as a biological and behavioural issue and neglects the environmental contributions to fracture and disability risk.[3,5]

Fracture risk arises from the combined effects of the interactions between bone fragility, hazardous exposures, and the mechanics of everyday injury. In other words, fractures are not only the result of weak bones but also of cumulative exposure to hazards in everyday environments. These risks are embedded in everyday environments, from the bathroom and the school corridor to playgrounds designed around speed, height and impact. These environmental hazards increase the likelihood of fractures, even when bone health and clinical care are optimized.[6]

We propose that the environmental design of childrens spaces require planning and resource allocation as part of OI care, comparable to pharmacological and surgical interventions. While we focus here on pediatric OI, similar environmental interventions could meaningfully reduce fracture and injury risk in children with conditions such as cerebral palsy, Duchenne muscular dystrophy, or ataxic syndromes. Furthermore, geriatric populations that are also at high risk for fractures, and in which there is a high prevalence of osteoporosis, Parkinsons disease, and other conditions, also benefit from these interventions.

The intentional design of spaces can predictably alter the frequency of hazard exposure and the likelihood of injuries. In safety science, the hierarchy of controls ranks methods of hazard reduction, from most to least effective: hazard elimination, safer substitutions, spatial redesign, rules and supervision, and, as a last line of defence, protective gear.[7] This perspective shifts fracture prevention from relying on individual vigilance toward systematic environmental design that proactively reduces fall risk and limits impact hazards. Moreover, the International Classification of Functioning, Disability and Health by the World Health Organization explicitly recognizes environmental factors as determinants of individual functioning, participation, and health.[8] Thus, OI management that ignores built environments remains incomplete.[9]

Children often lose access to play and peer participation, not because safer alternatives are impossible, but because systems default to restriction rather than redesign.

Across settings, small design decisions and routine policies are modifiable risk factors. At home, steep staircases without railings, slippery floors, and cluttered pathways increase fall risk; simple home modifications that make transfers and movement safer, such as grab bars, slip-resistant surfaces, and adequate space around key fixtures can reduce everyday hazards.[10] School environments can pose their own barriers, from poor circulation and inaccessible exits to playgrounds built around impact. Conversely, accessible classrooms and play spaces, with step-free routes and equipment that more children can use safely, support mobility and social inclusion.[11] In recreational settings, if most community sports are high-impact activities, many children with OI will find themselves with limited ways to participate, restricting their opportunities to move confidently and remain part of shared play.[9,12]

When spaces are not inclusive, the burden of mitigating fracture risk falls on the child and family, who are often advised to exercise caution by limiting high-impact activities and using mobility aids.[5] These measures, in turn, can lead to isolation.[13] Children often lose access to play and peer participation, not because safer alternatives are impossible, but because systems default to restriction rather than redesign. This tendency is rooted as much in liability concerns, as in constrained resources that limits investment in accessible, inclusive environments.[14] This same logic applies to seniors and individuals with disabilities. An equitable approach should mitigate risks by reducing hazards while preserving the individuals right to participate in school and community life.[15] Crucially, supervised and personalized activity programs can improve physical capacity and everyday function in children with OI.[3]

Implementation of inclusion strategies depends as much on policy and culture as on architecture. Unfortunately, attention to inclusive environmental design remains limited by cost, scarce OI-specific environmental research, and responsibility spread too thinly across sectors.[11,16,17] Furthermore, clinicians, educators, and community providers may overestimate injury risk for children with disabilities, and default to overly cautious restrictions rather than to personalized care focused on creating opportunities.[11,15] Schools and municipalities also face competing demands that delay accessibility investments, reinforcing a pattern in which risk is managed through exclusion rather than redesign.[11] Addressing these barriers requires coordinated policy, research, and design efforts that embed inclusion and safety in everyday environments.

Guiding families through identifying modifiable hazards and holistic environmental adjustments ensures that clinical care follows families home. Tracking OI patients physical activity and near-fall events, alongside fractures, would also improve the ability of health providers to advise families on common hazards and on strategies to mitigate risk in these areas. Universal design, which plans spaces to accommodate diverse needs from the outset, makes environments easier to move through and use safely. From step-free entry to clearer wayfinding, universal design maximizes accessibility across various populations. Adopting universal design at community-level institutions, such as schools and recreation centers, ensures that the responsibility for minimizing predictable hazards is institutionalized and does not rely on individual families advocacy. The implementation and prioritization of sustainable adaptive programming through comprehensive staff training and investment in accessible equipment also removes barriers to participation for families with OI diagnoses. Increased safety and risk mitigation alongside adaptive programming improves safe participation for children with OI and distributes the responsibility of care more evenly amongst the people around them who navigate the same environments.[18] Similarly to other accessibility requirements, public health and education systems should take on the responsibility of managing structured environmental audits to ensure adequate hazard reduction.[11] This approach has shown promising results in other contexts. For instance, when schools replaced unsafe playground equipment with equipment that met safety standards, playground injury rates decreased significantly.[19]

While environmental factors are widely recognized as important components of fracture risk, direct evidence linking specific environmental modifications to reduced fracture rates in OI remains limited. Future research should evaluate environmental interventions for their effects on injury risk, mobility, and day-to-day well-being; assess implementation performance, including whether these interventions can actually be afforded, adapted, and sustained in real settings over time; and develop OI-specific environmental guidance. Positioning environments alongside medical care aligns OI management with both medical and social models of disability, underscoring how non-clinical interventions spanning architecture, programming, and equipment can shape day-to-day functioning and offer a potential path to improved physical and mental well-being for children living with OI. What OI makes visible is a reality that applies to all bodies: environments shape health outcomes, making the case for accessible design not a niche concern but a universal one.

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