Lowest Heights of Floor Level Beds: Fall Velocity and Impact Force Analysis and Resulting Injuries.

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Aims
The aim of the study was to ascertain the difference between different low levels achieved by the use of floor level beds. Different suppliers of floor level beds claim that their height is optimal, but no clinical evidence exists to show which height is best. Commonsense would dictate that the lower the better but is 10cm better than 15cm or 25 cm and what is the outcome for the patient.

Background
A literature search was conducted to examine how floor level beds have developed and their widespread use in both hospitals and aged care institutions.

Methods
This study was conducted by examining the fall velocity, measured in meters per second and subsequent impact force, measured in newtons, and determining whether that force would cause injury in patients that have been hospitalized or are residents of aged care facilities. A 50kg mass was calculated to fall from 10cm, creating a baseline, at a rate of 1.4 meters per second ($v=\sqrt{2gh}$). The same mass was also examined at 15cm, 17cm, 20cm and 25cm showing an increase in fall velocity in each instance.

To calculate the impact force, the fall velocity 1.4m/s (10cm); 1.71m/s (15cm); 1.83m/s (17cm);1.98m/s (20cm) and 2.21m/s (25cm) were calculated into impact force, allowing for an absorption rate of 1 cm when the mass reaches the floor. This is to simulate the body absorbing some of the impact. In the baseline (10cm) case, a fall equates to 490 newtons of force on the body and a fall from 17cm equates to 735 newtons of force. The higher the force is caused by the increase in kinetic energy from the fall velocity. Further investigation was then conducted as to what injuries may result from the impact force.

Results
The results showed there was a significant difference between fall velocity when a patient fell from 10cm (baseline), 15cm (+22%above baseline), 17cm (+31% above baseline), 20cm (+41% above baseline) and 25 cm(+58% above baseline). The results of the impact force test showed a baseline of 490newtons (10cm) (baseline); 15cm(+50% above baseline); 17cm (+70% above baseline), 20cm (100% above baseline) and 25cm (150% above baseline).

Relevance to Clinical Practice
With at least one large study recommending the use of floor level beds in care environments for high falls risk patients and no clinical guidance as to the difference between beds heights, this study shows that there is a significant difference between beds that go to floor level and others that are lower than traditional hi-lo beds but not floor level. The study allows the reader to choose what lowest height would best suit their patient population.

Introduction

A body of evidence suggests that the risk of hospital or institution related injuries due to falls in acute and sub-acute hospitals and medium to high care, aged care institutions, increases hospital length of stay and the type of care required by patients. Studies have been conducted to show the frequency and impact of falls, reporting methods to highlight falls and the risk of falls and preventative measures to decrease the rate of falls in high risk patients.

To date, studies on the heights of beds used by patients with a risk of falling have centred around the mean height of the bed Huey-Ming and Chang-Yi 2008 or the use of floor level beds, also known as low-low and ultralow beds by Haines et al 2010 and Barker et al 2013 and 2009a and 2011 but have not discussed the optimum low height to negate the use of restraints and reduce the risk of injury should a patient fall from the bed.

Background

One of the methods discussed for the reduction of falls related injuries is that of bed height. Masud 2003 and Fonda et al 2006 found that 42-60% of inpatient falls were either bed related or patients were found in their bed spaces after a fall. Huey-Ming and Chang-Yi 2008 found that bed height was a factor in falls injuries with the beds in use in US hospitals at the time of the research were in the range of 25.42 inches to 26.34 inches.

Bollini et al 2010 examined a notification system and data collection Other studies have discussed the use of side-rails, also known as cot sides and bed rails, as a prophylactic measure to reduce falls from beds. The use of side-rails is highly contentious due to the entrapment caused by their use, the Hospital Bed Safety Workgroup 2003 recommended that side- rails should not be used where a patient could voluntarily get out of bed because they were considered a restraint. Capezuti et al 1996 found that the use of restraints was high is falls risk related residence in nursing homes in the US. In 1997, Todd et al examined the incidence of injury and death associated with the widespread use of side-rails in the hospital environment. The Todd et al study examined reports to the United States Food and Drug Administration regarding inpatient injuries and mortalities from 1985 to 1995. In 1999, Hangar et al further examined the link between side-rails and falls in hospitals in the US.

A number of studies have examined the relationship between fall injuries and the associated costs to hospitals and the healthcare system as a whole. Bawden 2008; Galbraith et al 2011; Moller 2005 and Hill et al 2010 .

Further works have examined the types and extent of morbidities caused by falls related injuries in both acute care and long term care facilities. Barker et al 2013 examined 356,158 inpatient records over a nine year period. Of the population, there were 3946 falls and 1005 fall related injuries. Barker et al used their research to establish the 6 Pack programme. A nine item falls risk assessment and six nursing interventions. One of the discussed nursing interventions was the use of low-low beds. For the purposes of this study we have used the term floor level beds.

Brand and Sundararajan 2010 conducted a 10 year cohort study using hospital patient data to determine the burden of risk with falls related injuries while De Paiva et al 2010 characterised patient falls according to hospital reports. Foss et al 2005 examined falls related injuries resulting in hip fractures, Hill et al 2010 identified that there were gaps in acute hospital reporting systems that did not measure all falls related injuries. Furthermore, Murray et al 2007 looked at the evidence from Australian acute and longterm facilities in relation to hospital acquired proximal femoral fractures.

Methodology

Although a body of work has shown the need for the use of explainer tools, assistive devices and floor level beds in the management of falls prevention, there has been no research on the effects of falls from low heights such as that from a floor level bed. Nor has there been any research on the velocity of falls from particular heights and the impact force sustained by falls and the likely subsequent injuries caused. Furthermore, there are several floor level beds on the market that range in lowest height from 10cm to 25cm. This research was focused on determining if there was any significant difference between falling 10cm or any of the other ranges.

The purpose of the study was to determine if there was any significant difference in fall velocity and impact force from a given height of floor level bed.. Research showed that most manufacturers of floor level beds use different methods to determine the lowest height of the bed. One model suggested that the measured the height from the floor to the top surface of the mattress platform, not including the mattress. This same model was adopted across the range of beds on the Australian market and determined the height range from 10cm, 15cm, 17cm, 20cm and 25cm.

The study was conducted in two parts. The first part calculated the fall velocity, measured in meters per second and subsequent impact force, measured in newtons, and determining whether bed height played a significant part in inpact force.

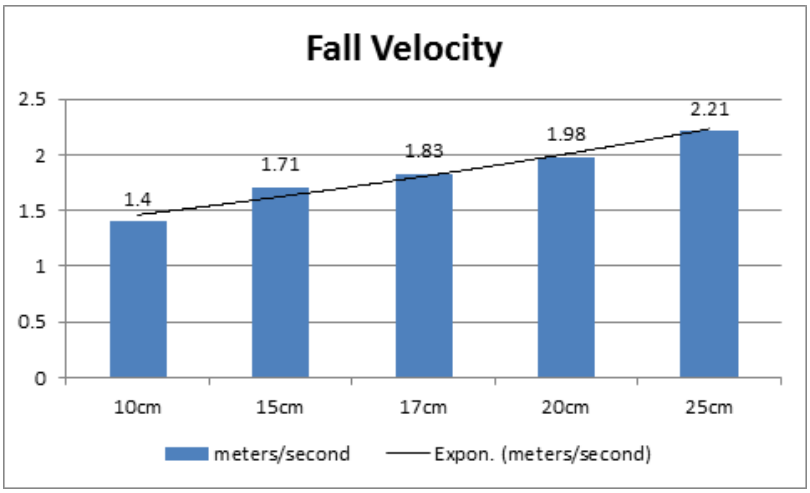
A 50kg mass was calculated to fall from 10cm, creating a baseline, at a rate of 1.4 meters per second using the formula ($v=\sqrt{2gh}$). This formula calculated the application of conservation of energy to a falling object which allows for the calculation of impact velocity (fall velocity) and kinetic energy just before impact.The same mass was also examined at 15cm, 17cm, 20cm and 25cm showing an increase in fall velocity in each instance using the same formula.

The second part of the study was to determine the impact force at the various calculated fall velocities, allowing for an absorption rate of 1 cm when the mass reaches the floor. The absorption rate is measured as distance travelled after impact. When this is known the impact force could be calculated using the work energy principle to create an average impact force measured in newtons. The formula used was $KE= ½ mv^2$ This is to simulate the body absorbing some of the impact. In the baseline (10cm) case, a fall equates to 490 newtons of force on the body. An increase in force was observed for different heights above the baseline. The higher the force is caused by the increase in kinetic energy from the fall velocity.

Study Findings

The study findings were not surprising although their net effect on the patient was cause for concern. In the first series of calculations, fall velocity was measured at 10cm, 15cm, 17cm, 20cm and 25cm by calculating the fall velocity of a 50kg mass.

Graph 1 shows the difference in fall velocity from each height.



From 10cm, which was established at the baseline, the measurement in meters per second was established at 1.40 meters per second. Each subsequent height was calculated using the same formula. In all cases a fixed weight of 50kgs was used.

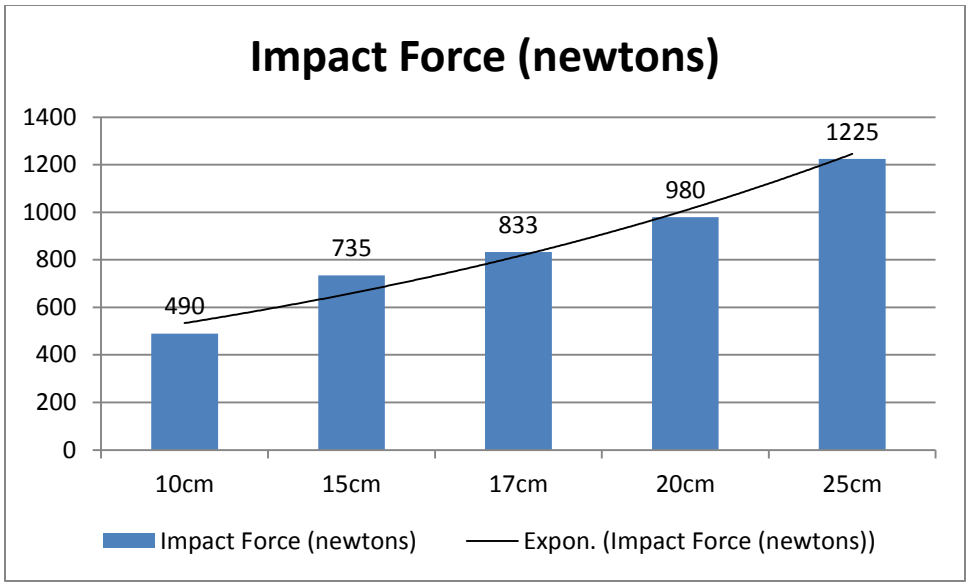
Table 1 shows the differences, expressed in percentages, from baseline of each height, using the same inputs.

Percentage Increase Above Baseline		
Fall Height	Fall Velocity (meters/second)	Percentage Increase Above Baseline
10cm	1.40	Baseline
15cm	1.71	22.1%
17cm	1.83	30.7%
20cm	1.98	41.4%
23cm	2.21	57.9%

In this case, the fall velocity from 15cm relative to 10cm (baseline) was 22.1% greater than the fall velocity from 10cm. Significantly, fall velocity increased by 30.7% at 17cm, 41.4% from 20cm and 57.9% from 25cm.

Fall velocity however is only part of the equation. An increase in fall velocity also impacts the impact force on the patient. The impact force effectively, is the cause of any injuries sustained in the fall and is of greater concern than fall velocity.

Graph 2 shows the impact force from each fall velocity. In each case a penetration force of 1cm was applied to the model to compensate for the bodies absorption of part of the force. This reduction in overall impact force was reflected in the table.



What was significant in Graph 2 was the rate of increase in impact force with each change in height. By adding 5cm to the baseline height of 10cm, ie 15cm, the impact force increased from 490 newtons to 735 newtons (50.0%).

Table 2 shows the increase above baseline, expressed as a percentage increase, and highlights the significance of impact force over the range of heights.

Impact Force Percentage Increase Above Baseline		
Fall Height (cm)	Impact Force (newtons)	Percentage Increase Above Baseline
10cm	490	Baseline
15cm	735	50.0%
17cm	833	70.0%
20cm	980	100.0%
25cm	1225	150.0%

Results
Barker et al 2009a/b, 2011, 2013, Haines et al 2010 have clearly demonstrated the need for the use of floor level beds with some patients where there is a risk of injury through falling. To date, although the use of floor level beds has been discussed, no clear definition of a floor level bed has been established.

The study found that the lowest possible height is ideal ie that brings the mattress as close to the floor as possible without actually touching it. The study found clearly that for those patients at falls risks and prescribed a floor level bed, should not be placed on a low bed but on a floor level bed that is within 100mm or less from the floor, measured from the floor to the top surface of the mattress platform. To not do this carries an increase in fall velocity and the increased likelihood of a greater injury should a fall occur.

Discussion
There is no international or Australian standard for bed height when it comes to floor level beds. All beds on the market in Australia should comply to ISO 60601-2-52: 2009 although many do not. Of the remaining beds on the Australian market, those that do not comply to 60601-2-52:2009 should comply with 60601-2-38: 1996 and all beds on the Australian market should be registered with the Australian Therapeutic Goods Administration as Class 1 products. Although ISO 60601-2-52: 2009 supersedes ISO 60601-2-38: 1996 neither study examines the floor level bed height nor recommends or states what could be considered as a floor level bed.

It is the hope of this study to allow the reader to determine what is the difference between the various lowest heights of floor level beds on the market and to allow an informed decision.

Hospitals, Aged Care facilities and home patients prescribed floor level beds should look at the data to determine that they find a bed that is registered, meets the international standards and that is as low as possible to the floor.

Conclusion
The lowest height of a floor level bed should not be underestimated. There is a significant difference (50%) in impact force by increasing the height by 5cm above baseline to 15cm.
If facilities purchase floor level beds in order to decrease the risk of falls injuries they should be guided to purchase the lowest possible bed rather than trying to purchase a bed that lowers to 15cm or higher in the hope that it could serve as an all purpose bed as this would not be a viable alternative and would lead to more expense as lower beds would still need to be purchased.

Although the literature did not show records regarding the type or height of beds or other equipment involved in falls, the increase in the impact force would suggest the likelihood of far greater injuries based on the height of the fall. Furthermore, the increase in fall velocity, even from a relatively small height increase, suggests the types of injuries sustained from a higher platform may be far greater in number and severity from even a slightly higher bed.

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