INFLUENCE OF WET SURFACES AND FALL HEIGHT ON PEDIATRIC INJURY RISK IN FEET FIRST FREE FALLS AS PREDICTED USING AN ATD

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INTRODUCTION

Falls in a feet first position show a high (> 40%) incidence of femur and skull fractures.[1] They are also common falsely reported in child abuse. Clinicians must evaluate the compatibility between reported history and presented injury in order to determine abuse. Therefore, it is of interest to understand those factors which may lead to a higher likelihood of injury in a fall.

Certain environment factors have been shown to correlate with injury risk in falls. Mott and others have shown that fall height was significantly related to the number of fractures.[2-4] The friction of the impact surface may also affect injury risk. The effect of a wet surface, though common among household accidents, has not been studied in detail as it pertains to injury risk in children.

Femur fractures and head injury are common clinical outcomes resulting from pediatric falls. In order to assess injury risk in falls, a Hybrid III anthropometric test dummy (ATD) was instrumented to measure head acceleration and femur loading profiles. ATDs were developed to evaluate the safety of occupant protection systems during high energy events, and commonly in motor vehicle crashes. Recently, their use has been extended to evaluating lower energy events.[5,6] Our study also examined the effect of surface friction and fall height for a free fall with a vertical initial posture.

METHODS

The free falls examined in this study had a vertical initial posture. This approximated jumping from a table, bed or couch with a feet first landing. The height of the fall was measured to the center of mass of the 3 year old ATD. Fall heights of 22, 35 and 47 inches were tested. Joint position was adjusted prior to each fall using a goniometer to insure the same initial posture. The joints were calibrated to the manufacturer specifications. The clothed ATD was instrumented with tri-axial head accelerometers and femur strain gages. Maximum HIC values were calculated for both 15 and 36 msec durations. The femurs were modified and instrumented to measure axial, torsion and bending loads. The readings from the strain gages on the femurs were converted to loading profiles using mathematically derived algorithms[7] based on the magnitude of the strain, the geometry of the rod and the material properties of the aluminum.

All data was sampled at 2000 Hz using a LabVIEW program developed specifically for this testing. Videotaping provided a visual record of the fall as well as a means to evaluate the similarity of gross motion kinematics. 10 drops were performed for each test condition.

RESULTS

Effect of Fall Height

The only significant change in head acceleration with regard to fall height was an increase for dry linoleum when the height was increased from 35 to 47 inches (p=0.05). Fall height did not significantly affect HIC_{15} or HIC_{36} values for falls onto either wet or dry linoleum.

Compressive femur loading increased significantly only for certain changes in fall height for dry linoleum. Femur bending moment increased significantly with increased fall height for both wet and dry linoleum for most fall height increases (Figure 1). Torsion loading did not increase significantly with fall height for wet linoleum. Only certain fall height increases caused increases in torsion for dry linoleum.

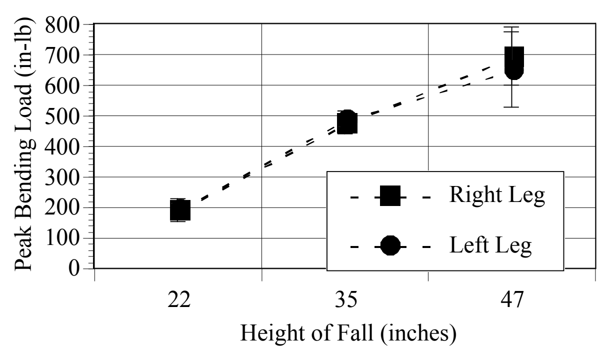

Figure 1: Femur bending load for dry linoleum

Effect of Dry Vs. Wet Linoleum

Head acceleration was found to increase significantly for a dry vs. wet linoleum surface only for the 47 inch fall height ($p=0.011$). HIC_{15} and HIC_{36} values increased significantly for dry vs. wet linoleum for both the 22 ($p<0.001$ for both) and 35 ($p=0.028$ and $p=0.011$ respectively) inch fall heights. The HIC_{15} value increased significantly for dry vs. wet linoleum for the 47 inch fall height ($p=0.05$), with HIC_{36} trending toward significance ($p=0.054$).

Compressive femur loading increased significantly for wet vs. dry linoleum for most height comparisons. Generally, bending loads increased for wet vs. dry linoleum. No significant difference was observed in torsional femur loading for wet vs. dry linoleum.

DISCUSSION

Fall height had the greatest overall effect on femur bending load. The average value associated with the 47 inch fall height was more than three times that of the 27 inch fall height for dry linoleum. For wet linoleum, the increase was less pronounced, but still present. This would indicate an increased risk for a femur fracture with increased fall height.

Femur bending moment was affected less by fall height than axial loading. The wet (vs. dry) linoleum showed an increased effect in axial load as the fall height increased. The values were similar for wet and dry linoleum at the lowest fall height.

Stanley conducted quasistatic compression loading experiments on 17 pediatric femurs.[8] He concluded that the upper load limit for a three year old is 196 lb_f. He suggested a 20% increase in strength for dynamic loading, bringing the ultimate strength to 235 lb_f. This value was exceeded only for wet linoleum at the 47 inch fall height. None of the other testing conditions exceeded this load limit.

Height of fall was shown to effect torsion loading only for the dry linoleum. The wet linoleum caused a considerable increase compared to dry linoleum in femur torque - approximately three times higher for both the 27 and 35 inch fall heights. The values were similar for both wet and dry linoleum for the 47 inch fall height. No data was found for comparison of pediatric bone strength in torsion.

For all fall heights, the dry linoleum produced the higher HIC values. Because the wet linoleum allowed the feet to slip out from underneath the ATD, the head was allowed to follow a more direct path to the impact surface. With dry linoleum, the ATD fell first into a sitting position and then backwards. This produced an upper body rotation that increased resultant head velocity which led to higher HIC values. The injury risks associated with HIC values can be approximated by comparing them to the HIC_{36} limit of 900 proposed by NHTSA for the Hybrid III three year old test dummy.[9] Our highest HIC_{36} value was 15 times lower than this proposed limit, indicating a low risk of contact-type head injury for any condition tested in this study.

Our findings suggest that there is relatively low risk of either contact-type head injury or femur fracture for falls up to 47 inches measured to the center of mass of the child when falling onto either wet or dry linoleum. Only falls onto wet linoleum from 47 inches were found to produce compressive femur loads close to the proposed fracture limit. These findings agree with other studies that have examined medical records to determine the injury risk for low level falls.[10] This study did not examine the role of surface friction on the initiation of the fall. Work by Redfern et al has shown that a decrease in surface friction can lead to an increased risk of a slip initiation and, potentially, a fall.[11]

ATDs were developed to examine biomechanics and injury risk for high energy events. Their biofidelity for lower energy falls has not been validated and thus is a limitation of our study. Furthermore, the biofidelity of our instrumented ATD femur has not been validated. Additional studies aimed at improving the biofidelity of the 3 year old lower extremity are necessary before being able to completely assess fracture risk. The joint range of motion for the Hybrid III ATD also varies from a child and therefore is another limitation of our study. This limited range of motion likely affects the fall dynamic and, consequently, femur loading and head acceleration. The results of our study are therefore limited to investigating trends in the outcome measures as they relate to the parameters of fall height and wet vs. dry surfaces.

CONCLUSIONS

The purpose of this study was to examine the effect of a wet surface and fall height on certain biomechanical measures in a child during free fall. Femur fractures and head injuries are often seen in abuse cases and an understanding of the relative risks of these injuries for short distance falls would provide the emergency department clinician with a valuable tool when attempting to determine if injuries matched case history. Simulating falls using a Hybrid III ATD produces repeatable, objective data to measure trends in femur loading and head acceleration values. Additional testing to evaluate the biofidelity of the Hybrid III for low energy events is required before measured data can be compared directly with known injury thresholds, but knowledge of the effect of fall height and impact surface properties illustrates the importance of a detailed and accurate history in attempting to determine whether injuries were accidental or inflicted.

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