HP 01-1

# The Children's Hospital *of* Philadelphia

34th Street and
Civic Center Boulevard
Philadelphia, Pa 19104-4399
215-590-1000

December 18, 2000



Ann Brown
Chairman
United States Consumer Product Safety Commission
Washington, DC 20207-0001

RE **Petition for regulation of bicycle handlebars**

Dear Ms Brown,

I am writing to alert you to a potentially preventable form of serious injury – handlebar-related injuries to abdominal organs It has long been known that bicycle handlebars pose a risk of pancreatic, intestinal, renal, liver, and splenic injuries, particularly to young children Our recent study demonstrates that these serious injuries occur in the setting of minor incidents – falls from bicycles not involving motor vehicle crashes (see attached manuscript) The discordancy between the minor circumstances (low-speed falls) and the serious nature of the injuries suggest that the cause of the injury was the bicycle itself We further explored the circumstances and discovered that the handlebars were acting as blunt spears and, as such, were causing the injuries upon impact

Our further research indicates that handlebars can be designed that will minimize the risk of these injuries (see attached manuscript) Our handlebars dissipate the impact energy and spread the forces over a larger surface area so that forces transmitted by the end of the handlebar to the abdominal organs during impact are reduced to below known injury tolerance levels We are not suggesting that our design is the optimal design for a safer handlebars; rather, we are demonstrating by our design that safer handlebars are feasible and should be required on all new bicycles and that retrofit solutions for existing bicycles should be explored

By this letter, I am petitioning the Consumer Product Safety Commission to regulate the safety of handlebars by way of a performance standard regarding energy dissipation and distribution during impact.

Thank you in advance for your thoughtful consideration of this very important issue

Sincerely,

Flaura Koplin Winston, MD PhD

Director,
TraumaLink The Interdisciplinary Pediatric Injury Control Research Center
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# Hidden Spears: Handlebars as Injury Hazards to Children

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ABSTRACT *Objectives* To delineate the mechanism of serious bicycle handlebar-related injuries in children and make recommendations for preventive strategies

*Methods* Prospective cross-sectional surveillance system of seriously injured child bicyclists supplemented by in-depth, on-site crash investigation to delineate specific injury mechanisms Interdisciplinary analyses involved engineers, clinicians, epidemiologists, and biostatisticians

*Setting.* The emergency department and in-patient trauma service of an urban level one pediatric trauma center between October 1995 and September 1997

*Participants* Patients under 18 years of age who were treated for serious bicycle-related injuries (Abbreviated Injury Scale scores of 2 or greater)

*Results* The surveillance system identified two distinct circumstances for serious child bicyclist injury 1) handlebar-related injuries associated with minor incidents (falls from bicycles) and 2) nonhandlebar-related injuries associated with severe incidents (bicycle-motor vehicle crashes) Crash investigations explored the minor incidents that resulted in serious handlebar-associated injuries In the typical mechanism, as the child lost control of the bicycle and began to fall, the front wheel rotated into a plane perpendicular to the child's body The child then landed on the end of the handlebar resulting in serious truncal injuries

*Conclusions* A discordancy exists between the apparently minor circumstances and serious injuries sustained by child bicyclists who impact bicycle handlebars Recognition of the mechanism of handlebar-related injuries might aid the practitioner in early diagnosis of serious abdominal injuries in child bicyclists This injury mechanism may be avoided through bicycle redesign that would involve both limiting rotation of the front wheel and modifying the ends of handlebars. An integrated approach involving a surveillance system to identify an injury hazard supplemented by in-depth, on-site crash investigations effectively provided the detailed mechanism of injury needed to develop interventions *Pediatrics* 1998,102.596–601, *bicycle, handlebars, children, abdominal trauma, injury prevention, injury mechanism*

ABBREVIATIONS ICE, Injury Circumstance Evaluation, EMS, Emergency Medical Services, AIS, Abbreviated Injury Scale, ISS, Injury Severity Score MAIS, Maximal AIS

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PEDIATRICS (ISSN 0031 4005) 

A primary goal of injury control research is to develop interventions that will reduce the incidence and severity of injuries The process of translating research into interventions involves identifying injury hazards and elucidating the etiology of the hazard in sufficient detail for those who will develop the interventions Application of this process has resulted in the identification of head injury as a significant source of morbidity and mortality in child bicyclists and resulted in the development of the bicycle helmet [1–6]

Recent reports[7–9] indicate handlebars as another source of injury among child bicyclists even among low-speed crashes [7] Effective countermeasures, however, have not yet been developed primarily because of the limited understanding of the injury mechanism The majority of reports of handlebar-related injuries have been limited to descriptions of treatment strategies, operative techniques, and course of recovery Impact with handlebars has been documented as producing traumatic abdominal wall hernia,[10–13] renal, intestinal, liver, splenic, and pancreatic injuries,[7–9 14–17] abdominal wall rupture,[18] abdominal aorta rupture,[19] transection of the common bile duct,[20] traumatic arterial occlusion,[21] groin injuries,[22 23] and even death [24] Underlying organ injuries are often occult, as external bruising is infrequently present, and the signs and symptoms of organ injury do not present for hours [7] Although these reports have recognized the role of the handlebar in child bicyclist injury, there is insufficient information regarding the detailed mechanism of injury

For effective interventions to be developed, the mechanism of handlebar-related injury must be understood In the current study we proposed to 1) identify the basic circumstances surrounding child bicyclist injuries through use of a surveillance system and 2) elucidate the detailed mechanism of injury with on-site, in-depth crash investigations incorporating the expertise of engineers, epidemiologists, clinicians, and biostatisticians

## METHODS

### Injury Circumstance Evaluation (ICE) Study of Bicyclists, Pedestrians, and Motor Vehicle Occupants

The goal of the ICE Study is to identify significant injury hazards to children and to elucidate the mechanism of the injury hazard with sufficient precision to allow the development of interventions To achieve this goal, the ICE Study combines a prospective cross-sectional surveillance system of injured children and on-site in-depth crash investigations to identify specific injury mechanisms Previous results of the ICE Study revealed the mechanism of airbag-related deaths and serious injuries in children.[25-27]

The ICE Study recruits pediatric patients < 16 years of age who were transported by Emergency Medical Services (EMS) personnel and treated for injuries sustained as bicyclists, pedestrians, or motor vehicle occupants at a level one urban pediatric trauma center servicing a five-county region. Excluded from the ICE Study are children for whom a history cannot be obtained. Consent for inclusion in the study is obtained according to a protocol approved by the Institutional Review Board of The Children's Hospital of Philadelphia.

The ICE surveillance system incorporates data collected from self-administered surveys completed by EMS personnel upon delivery of injured children to the emergency department and surveys administered by two trained parahealth professionals to children, witnesses, and relatives upon the child's admission to the inpatient trauma service for treatment of his or her injuries. For a given child, multiple respondents complete surveys to obtain the most complete history. Discordant responses are resolved by follow-up interviews. Surveys were developed by incorporating the expertise of engineers, clinicians, and epidemiologists through the approach of biomechanical epidemiology.[28] Biomechanical epidemiology is a new concept that combines the strengths of engineering, medicine, and epidemiology through the design, execution, and analysis of injury research.

The ICE surveillance system is analyzed to identify circumstance-injury patterns. Cases representing these patterns are then subjected to on-site, in-depth crash investigation by Dynamic Science, Inc, (Washington, DC) a professional crash investigation team. Data collected by the investigators include scene and vehicle evidence and child bodily contact points that are used to determine how the injury event occurred and the kinematic movement of the child in response to the event. These data are analyzed independently by two professional investigators to elucidate detailed mechanisms of injury.

Reconstruction of the injury-producing events involves standardized procedures that relate scene and vehicle evidence to the injuries received by the child. Differences in interpretation are resolved by a third investigator. Protocols are available on request.

Descriptions of the injuries sustained are obtained from the medical record and coded according to the *International Classification of Diseases, 9th Clinical Modification*[29] and Abbreviated Injury Scale (AIS) codes (see definition below) by two separate individuals (trained research assistants), one of whom is blinded to injury mechanism. Discrepancies are resolved by joint review of the medical records. Additional information obtained from the medical record includes gender and age.

The AIS[30] and the Injury Severity Score (ISS)[31] were used to classify bicyclist injury severity. The AIS rates the severity of an anatomic injury from 1 (minor injury) to 6 (fatal injury) for each of six body regions: head/neck, face, chest, abdomen, extremities/pelvic girdle, and external. A score of 0 was assigned to patients who sustained no injuries. Because multiple injuries might occur within one or several body regions, Maximal AIS (MAIS) was defined for each body region and overall for any body region and was recorded for each subject. All subjects in this study had a MAIS of ≥2. The ISS was developed to account for overall injury severity. ISS is the sum of the squares of the three highest AIS scores, thereby accounting for multiple injuries sustained.

## ICE Surveillance Data Collection for the Current Study

The subjects for the current study were the subset of the ICE Study population who were seriously injured bicyclists (AIS ≥2) treated at our regional trauma center. Only those more seriously injured children were included because they constitute a well-defined population who are triaged to the center for definitive trauma care.[2,31]

As mentioned, the ICE Study uses a series of surveys to obtain detailed trauma histories that describe the injury circumstances. Answers used in the current study involve time of incident, descriptions of the sites of body impact, bicycle crash type (eg, struck and thrown on motor vehicle), direction of impact and fall, surfaces impacted, speed of vehicles, and other circumstance information. Specific questions addressing handlebar involvement in injury included anatomical descriptions of where the handlebars made impact with the child's body and what object the child's body first made impact. The questionnaire is available from the authors on request.

Child bicyclists were systematically classified into two impact groups based on survey responses. The handlebar group was composed of those whose survey responses indicated that they made impact with the handlebar. The remaining bicyclists were classified into the nonhandlebar impact group.

Survey responses were systematically classified into three event severity categories. Bicyclist collisions with a moving motor vehicle were classified as severe, bicyclist collisions with a stationary object (eg, pole or parked vehicle) or another bicyclist were classified as moderate, bicyclist collisions in which the child simply fell off the bicycle were classified as minor.

## Statistical Analyses

Gender was compared between the two impact groups (handlebar and nonhandlebar) by a Fisher's Exact test. Age was compared using a Student's $t$ test for independent samples. Distribution of the most severely injured body regions was compared using an exact $\chi^2$ test. MAIS and event severity were compared between impact groups using a Kruskal–Wallis Exact test. ISS was compared between impact groups using a Mann–Whitney $U$ test. Analyses were conducted using SPSS and StatXact. Statistical significance was set at $P < .05$.

## On-site, In-depth Crash Investigations for the Current Study

Analysis of the surveillance data identified minor bicycle-related incidents resulting in serious injuries. Cases with this discordant circumstance-injury pattern for which a bicycle was available for inspection and consent was obtained were identified for targeted study using on-site, in-depth crash investigations for the determination of injury mechanisms. Specialized data collection forms were developed to record scene, vehicle, and injury data for injured child bicyclists and were used for the current study.

# RESULTS

From October 1995 through September 1997, 107 bicyclists with MAIS 2 or greater injuries were identified from the ICE Study and formed the cohort of seriously injured child bicyclists for the current study. Over half (59%) of the 107 children in the study had multiple injuries. Overall, the 107 children in the study sustained a total of 190 injuries. These injuries were distributed by body region as follows: 46 head/neck injuries, 7 facial injuries, 5 chest injuries, 18 abdominal injuries, 61 extremity injuries, and 53 external/superficial injuries.

The distribution of the most severely injured body region for each child based on handlebar impact grouping is presented in Table 1. The handlebar impact group is comprised of children with injuries distributed among most body regions, but the majority of serious injuries occurred within the abdominal region. The nonhandlebar impact group had injuries distributed among all body regions, but the most severe injuries were to the extremities and head ($P < .0001$).

The abdominal injuries in the handlebar impact group were as follows: six splenic lacerations, two liver lacerations, three kidney injuries (two lacerations and one hematoma), and two pancreatic lacerations. Other handlebar impact-related injuries included one pneumothorax, one thigh impalement, one closed head injury with basilar skull fracture, and one radius fracture.

The distribution of demographic variables, MAIS, ISS, and event severity between the two impact

TABLE 1 Distribution of Most Severe Injuries by Impact Type of Injury

| Body Region | Handlebar Impact | Non-handlebar Impact | Total* | P Value |
|---|---|---|---|---|
| Head/neck | 1 | 29 | 30 | < 0001 |
| Face | 0 | 1 | 1 | |
| Chest | 1 | 1 | 2 | |
| Abdomen/pelvis | 13 | 3 | 16 | |
| Extremities | 2 | 47 | 49 | |
| External | 0 | 1 | 1 | |
| Equivalent head and face† | 0 | 1 | 1 | |
| Equivalent head and chest† | 0 | 1 | 1 | |
| Equivalent head and extremity† | 0 | 6 | 6 | |

* The 107 bicyclists represented had multiple injuries, but the body region corresponding with the most severe injury a bicyclist sustained was used for this table

† Categories represent body regions which sustained the same injury severity and were equivalently the most severely injured body regions

groups is presented in Table 2 Overall, the majority of injured bicyclists were male (78%) and the average age was 10 years There were no significant differences in gender and age for the handlebar impact and nonhandlebar impact groups The handlebar and nonhandlebar impact groups had similar severities of injury as demonstrated by similar MAIS and ISS ($P =$ 51 and $P =$ 28, respectively) Median MAIS and ISS were 2 (range, 2–4) and 5 (range, 4–16), respectively, in the handlebar impact group and 2 (range, 2–5) and 5 (range, 4–34), respectively, in the nonhandlebar impact group

There was a significant association between the event severity and impact group ($P <$ 0001) No severe events (bicycle-motor vehicle crashes) resulted in handlebar impact, rather, the more minor events (falls from bicycles) were associated with handlebar impact

Thirteen (76 5%) of the handlebar impact-related crashes occurred as a result of five minor crash types 1) when the bicyclist lost balance after hitting a discontinuity in the riding surface (sidewalk pothole, grass-sidewalk interface, or curb), 2) when the child braked suddenly, 3) after the chain disengaged from the wheel (chain pop), 4) during a performance of a stunt, or 5) when the rider suddenly turned the front wheel The four remaining handlebar impact-related crashes occurred under moderate crash circumstances in which the rider made impact with a stationary object or other bicyclist

In both minor and moderate circumstances, upon falling from the bicycle, the child made impact with the handlebar end, the stemcrown (Fig 1), or crossbar (Fig 2) In 12 (70 6%) of the cases, the child made impact with the end of the handlebar Two made impact with the stemcrown or crossbar In the remaining three specific handlebar impact was unknown

Surveillance data regarding handlebar-related injuries were confirmed and supplemented by in-depth, on-site crash investigations Seven cases of handlebar-related injury were selected for investigation because the bicycle was available for inspection and consent was obtained Events investigated included three bicycle mechanical failure, two loss of control, and two stunts All of the bicycles were appropriately sized for the riders Four subjects impacted the handlebar ends, 1 subject impacted the stemcrown, 1 subject impacted the crossbar, and 1 subject impacted either the handlebar end, the crossbar, or both Five of the bicycles were stunt-type, two of which were self-assembled with parts from a variety of bicycles The handlebars on the five stunt-type bicycles were regular handlebars with an exaggerated curvature toward the rider The handlebars on the other two bicycles were the same regular handlebars with less curvature toward the rider Protective rubber covering was present on six of the handlebar ends, none had shock-absorbing foam padding on the handlebar ends One bicycle had exposed metal handlebar ends (Fig 3) The stem-

TABLE 2 Patient Frequency and Injury Characteristics by Impact Type

| Variable | Handlebar Impact | Non-handlebar Impact | Total* | P Value |
|---|---|---|---|---|
| Gender | | | | 0 76 |
| Male | 14 | 69 | 83 | |
| Female | 3 | 21 | 24 | |
| Age (y) | | | | 0 58 |
| Mean | 10 | 10 4 | 10 34 | |
| SD | 3 | 3 3 | 3 21 | |
| MAIS† | | | | 0 51 |
| 2 | 9 | 56 | 65 | |
| 3 | 6 | 26 | 32 | |
| 4 | 2 | 7 | 9 | |
| 5 | 0 | 1 | 1 | |
| Median | 2 | 2 | | |
| Range | 2–4 | 2–5 | | |
| ISS‡ | | | | 0 28 |
| Median | 5 | 5 | | |
| Range | 4–16 | 4–34 | | |
| Event Severity | | | | < 0001 |
| Minor (Fall) | 13 | 18 | 31 | |
| Moderate (Other collision) | 4 | 17 | 21 | |
| Severe (Motor vehicle collision) | 0 | 55 | 55 | |

* 107 bicyclists are represented

† Represents the most severe injury a bicyclist sustained

‡ Represents overall injury severity

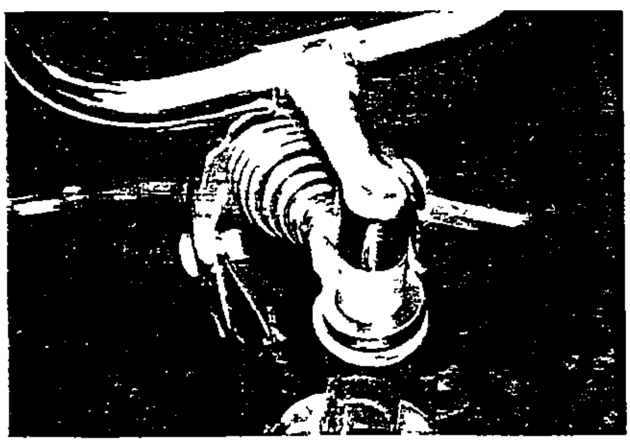

Fig 1 Stemcrown onto which a bicyclist fell resulting in a pancreatic fracture

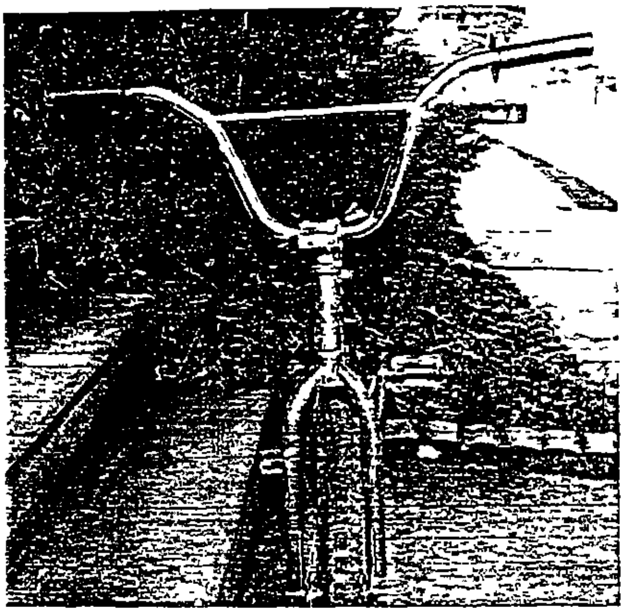

Fig 2. Crossbar onto which a bicyclist fell, resulting in a flail chest and pneumothorax

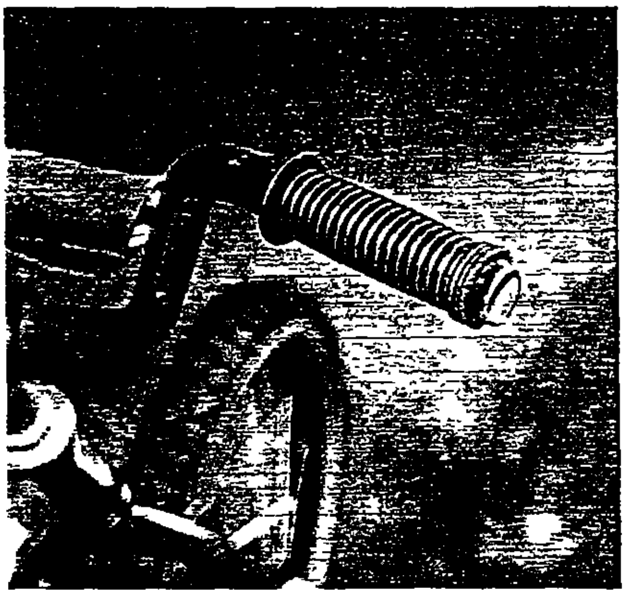

Fig 3 Exposed metal handlebar end onto which a bicyclist fell resulting in a liver laceration

crown (Fig 1) and crossbar (Fig 2) onto which two of the bicyclists fell were not protected or padded.

One mechanism of injury was common to four of the seven bicyclists: one stunt rider, two bicyclists who lost control, and one whose bicycle sustained mechanical failure. As the child began to fall, the front wheel rotated into a plane perpendicular to the child's body. The child then landed on the end of the handlebar and serious truncal injuries resulted. The injuries sustained included two liver lacerations, one renal laceration, and one splenic laceration. None of these involved penetration of the skin and five of the seven bicyclists had external bruising.

In two cases of mechanical failure, the child fell and landed on the crossbar or stemcrown. Injuries sustained included a flail chest with pneumothorax and a pancreatic fracture, respectively. In the case involving a rider performing a stunt it could not be determined if the impact was with the crossbar or the handlebar end. In this case, a splenic laceration resulted. A typical case of impact with the handlebar end is presented below.

A 6-year-old boy arrived at our hospital via interhospital helicopter transport for treatment of a liver laceration. The child was riding his stunt bicycle at 4 miles per hour when his bicycle hit a discontinuity in the sidewalk. As the front tire began to cross-the concrete-grass interface, the child lost momentum, causing the front wheel to turn toward the right exposing the child's abdomen to the right handlebar, whose end was exposed rusted metal (Fig 3). He subsequently lost his balance and fell onto the right handlebar, together the bicycle and child fell to the ground. The child then lay at rest until a neighbor came over and helped him.

The child's mother called the pediatrician and described her son's abdominal pain. The pediatrician advised the mother to give her son acetaminophen and call back in a couple of hours. Disregarding the physician's advice, she brought her son to a local emergency department where an abdominal computed tomogram revealed a liver laceration that virtually transected the right and left hepatic lobes. He was immediately transferred by helicopter to The Children's Hospital of Philadelphia.

On arrival at our hospital, his heart rate was 124, respiratory rate was 32, and his blood pressure was 129/68. His Glasgow Coma Score was 15 and his trauma score was 15 (−1 respiratory rate). On admission, he was febrile and the physical examination revealed a tender, distended abdomen. Laboratory studies were significant for hemoglobin of 10 g/dL (nL: 11.5–15.5 g/dL), sodium of 152 mmol/L (nL: 136–142 mmol/L), potassium of 3.32 (nL: 3.8–5.0 mmol/L), ionized calcium of 1.12 mmol/L (nL: 1.15–1.34 mmol/L), plasma glucose of 205 mg/dL (nL: 65–121 mg/dL), and albumin of 2.2 g/dL (nL: 3.5–5.2 g/dL). He was initially admitted to the pediatric intensive care unit, but because of tachycardia he was fluid-resuscitated and brought to the operating room where he received 3000 mL of packed red blood cells, 3000 mL of crystalloid solution, 1800 mL of fresh frozen plasma, and 650 mL of platelets. He underwent an immediate exploratory laparotomy during which a right hepatic lobecetomy and cholecystectomy were performed. His total blood loss was >3 liters. A T-tube was placed in the common bile duct, and he was returned to the pediatric intensive care unit. His postoperative course was initially unremarkable with discharge to home 11 days later after T-tube removal.

One week after discharge, the patient was readmitted complaining of abdominal pain and fever. An ultrasound revealed fluid collection in the right upper quadrant of his abdomen. Laboratory values were significant for a white blood cell count of 21.3 thou/$\mu$L (nL: 6.0–17.0 thou/$\mu$L), platelets of 659 thou/$\mu$L (nL: 150–400 thou/$\mu$L), segmented neutrophils of 82% (nL: 30–55%), and lymphocytes of 14% (nL: 30–55%). He was started on intravenous fluids and antibiotics His fever continued A chest radiography revealed a right pleural effusion whose drainage slowly tapered during his hospital stay Fourteen days after admission he had minimal abdominal pain, and he was discharged to home

## DISCUSSION

This is the first study of pediatric handlebar-related injuries in which detailed circumstance and clinical data were collected prospectively to delineate the mechanism of this injury in sufficient detail for redesign of handlebars This study used effectively a surveillance system supplemented by on-site crash investigations to delineate the typical injury mechanism in which a child, who lost control of the bicycle, began to fall During the fall, the front wheel rotated into a plane perpendicular to the child's body The child then landed on the end of the handlebar resulting in serious truncal injuries Additional handlebar impacts resulted from bicycle mechanical failure In these cases the child fell and landed on an unpadded stemcrown or crossbar

Serious bicyclist injury from handlebar impact occurs with a history of an apparently minor incident, usually a fall A previous case-control study of non-severe child bicyclist injuries similarly found that minor circumstances, including low bicycle speed and riding on a sidewalk, were associated with emergency department visits However, an explanation for these findings was not provided [34] In the present study's cohort of child bicyclists, 16% of serious injuries resulted from handlebar impact and none involved collision with a motor vehicle This is in contrast to the remaining 84% of serious child bicyclist injuries that primarily involved bicycle-motor vehicle collisions

The frequency of handlebar impact in producing serious injuries in child bicyclists was confirmed by a multi-institutional study of child bicyclist injuries reported to the National Pediatric Trauma Registry Ten percent of the bicyclists enrolled in that study impacted the handlebars In the National Pediatric Trauma Registry Study, none of the handlebar-related injured subjects sustained a head injury Furthermore, among the nonhead-injured bicyclists, these handlebar impacts accounted for 22% of the reported injuries, thereby representing a significant source of injury In agreement with the results of our study, none of these handlebar-related events involved a motor vehicle (Baker SP, Fowler CJ, Winston FK, Li G, DiScala C *Sequelae of Head Injury in Child Bicyclists, Phase II* Submitted to The George Snively Research Foundation The Johns Hopkins University Center for Injury Research and Policy October 1997)

Our results also appear relevant to the findings of Clarnette and Beasley[7] who found that serious handlebar-related injury involves low-velocity crashes and often results in abdominal injury that may not be symptomatic until several hours after the injury Because abdominal injuries can be occult, they may be missed by the diagnosing physician and the need for a thorough trauma history is essential to maximize efficient care [35] The case report presented in this study specifically highlights how handlebar injuries can become a missed or delayed diagnosis Recognition of the mechanism of handlebar-related injuries might have aided the pediatrician in early diagnosis of a liver laceration The evaluating physician should ask a series of questions regarding the bicycle crash in an effort to determine if the handlebar was involved in producing injury If a handlebar were implicated in the injury causation, a follow-up history and physical eliciting signs and symptoms of shock should be pursued

The case report of the 6-year-old child also brings attention to the use of the stunt bicycle in the home environment Five of the bicycle crashes subjected to in-depth investigation involved stunt-like bicycles The potential hazard of stunt bicycles in producing handlebar-related injuries is corroborated by the work of Sparnon et al in 1982[23] and Sparnon and Ford in 1986[16] in which stunt bicycles were implicated in scrotal injuries and intra-abdominal system injuries, respectively These studies and the results of the current study elicit concerns about whether the home environment is appropriate for stunt bicycle use

In addition to the type of bicycle, the size appropriateness of the bicycle for the child is important Improper bicycle sizing may impede the child's handling of the bicycle, potentially predisposing the child to falling, and may expose more of the child's trunk to the handlebar Although improper bicycle sizing was not apparent in this study among those cases subjected to in-depth crash investigation, the potential consequence of improperly sizing a bicycle for a young rider must be considered

The importance of the trauma history has been demonstrated previously elsewhere Trauma histories focusing on discordancies between injury mechanism and actual physical damage to the victim have been essential in the detection of child abuse[36,37] and domestic violence [38] Similarly, trauma histories have identified the role of air bags in child occupant fatalities in low speed crashes [25–27] The emergency department can provide essential information for injury prevention and treatment if a sufficiently detailed trauma history is obtained

This study was limited to a single level one pediatric trauma center and included only children with serious injuries to be able to identify specific circumstances associated with these injuries To obtain incidence and prevalence data regarding bicycle handlebar-related injuries, further study should include data from the community regarding children with no or minor injuries [33,39] Additionally, the sample size of the study does not allow for subgroup analysis of specific handlebar designs and their role in producing bicyclists' injuries Previous studies performed on handlebar type were limited to describing the presence of protective padding on the ends of the handlebars [8] Further study incorporating a larger data set and expansion of parameters might permit the development of specific recommendations Additionally, a larger study of the serious handlebar injuries should be conducted to determine whether manufacturers should be encouraged to produce bicycles with curved handlebars, especially for small and younger riders Such a study could also be used to explore the benefit of design limitations such as limitation of rotation of the front wheel

Handlebar-related injuries could potentially be avoided by curving handlebar ends away from the rider and padding the handlebar ends These handlebar redesigns are recommended for all bicycle types Limitation of the front wheel rotation is also recommended, but it is recognized that restricting the free rotation of the front wheel might not be acceptable to some stunt bicycle competitors Consequently, consideration should be given to limiting the use of stunt bicycles to controlled competition settings with experienced riders

Clinicians can play an important role in the prevention and treatment of handlebar-related injuries Through anticipatory guidance, clinicians can educate parents about choosing and maintaining their child's bicycle This education might include proper sizing of the bicycle to the child, appropriate type of bicycle for the child's age and skill level, maintenance of the bicycle to prevent mechanical failure, and maintenance of handlebar guards If a child bicyclist is injured in a fall, clinicians should elicit a complete trauma history from EMS personnel, children, and witnesses Identification of handlebar impact may be essential to identifying serious occult truncal injuries in child bicyclists

## ACKNOWLEDGMENTS

This work was funded by Agency of Health Care Policy and Research Grant 5 U01 HD32828 as part of the Emergency Medical Services for Children Program

We thank The Children's Hospital of Philadelphia Trauma Service, Philadelphia Fire Rescue Frances Bents and Robert Schaar at Dynamic Science, Inc, Elisa Moll, Craig Rineer, Harry Jenkins, and Esha Bhatia for their contributions to this research

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PROTECTING THE CHILD'S ABDOMEN A RETRACTABLE BICYCLE HANDLEBAR

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Running head A retractable bicycle handlebar

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In press – *Accident Analysis and Prevention*

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**ABSTRACT**

A surveillance system in the Emergency Department of a Level 1 pediatric trauma center previously identified minor bicycle crashes as a cause of serious child abdominal injury A discordancy exists between the apparently minor circumstances and serious injuries sustained by child bicyclists who impact bicycle handlebars. The objective of this work was to redesign the bicycle handlebar to reduce the forces transmitted to the child's abdomen during an impact with the handlebars.

A retractable handlebar consisting of a spring-mass-damper system was designed to retract and absorb the majority of energy at impact. Since the child remains in contact with the bar after impact, the retracting system also includes a mechanism to damp the outward motion of the handlebar This prototype will reduce the forces at impact by approximately 50% in a collision similar to those discussed above

A unique methodology of translating research findings into product design produced a novel handlebar that absorbs significant energy that otherwise would be transferred to the child's abdomen when impacting the handlebar

Keywords: abdominal injury, product design, bicycle safety

## INTRODUCTION

Impact with the handlebar in slow speed bicycling crashes has been identified as a mechanism of life threatening truncal injuries in children A thirty-year period of study of children's abdominal injuries (348 cases) showed that the predominant cause (104 cases) of abdominal injury in children age 6-10 years was bicycle accidents (Bergqvist, et al, 1985) In a study at a pediatric trauma center from 1980-1994, the largest percentage (27%) of pancreatic injury in children was a direct result of bicycle handlebars (Arkovitz, et al., 1997). A recent report documented a fatal delayed rupture of the abdominal aorta due to impact with the bicycle handlebar (Tracy, et al., 1996)

A multi-institutional study of child bicyclist injuries using the National Pediatric Trauma Registry as a data source revealed that ten percent of the bicyclists enrolled impacted the handlebars and that none of those that impacted the handlebars sustained a head injury Furthermore, of all children without head injuries, 22% of the injuries were due to handlebar impact. (Baker et al, 1997)

In our previous work, a prospective surveillance system in the Emergency Department of a Level 1 pediatric trauma center was used to identify children with this injury pattern and specifics of the injury mechanism were delineated through accident reconstruction (Winston, et al , 1998) The most common scenario was as follows the child was riding forward when he/she came into contact with an obstructing object (i e curb, bump, rock, etc ) Upon contacting the object, the forward motion of the bicycle was stopped and, in order to gain his/her balance. the child turned the handlebar perpendicular to his/her abdomen. The child's momentum carried him forward impacting the handlebar Following the forward motion the child fell to the ground while still in contact with the handlebar The distal end of the handlebar collided with the ground, forcing the proximal end of the bar into the child's abdomen causing serious life-threatening injuries to the liver, spleen, and pancreas (Figure 1)

No effective countermeasures have been developed to prevent these debilitating injuries The goal of this study was to use a unique methodology to translate our research findings of handlebar injuries into the design of a novel handlebar system. This system would be able to absorb energy and reduce the force transferred to the child's abdomen in bicycle handlebar collisions

## METHODS

The child's body mass, the mass of bicycle, and specific dimensions of the bicycles were abstracted from the accident reconstruction reports from our previous work discussed above (Winston et al, 1998). Impact forces from a typical crash were determined using the equations of physical motion

Initially, the person (p) is riding the bicycle (b) at an initial velocity of $v_{bi}$ When the child is initially thrown from the seat into the handlebar, a second system is established where there is only the momentum of the person due to the complete stop of the bicycle The velocity of the child's initial impact with the handlebar ($v_{impact1}$) is equal to the initial velocity of the bicycle ($v_{bi}$)

$$V_{impact1}=V_{bi} \quad (1)$$

The subject and the bicycle then fall toward the ground where upon impact, a significant force is exerted by the handlebar upon the subject. The force associated with the handlebar is given by

$$F_{handlebar} = F(h)\sin\theta \quad (2)$$

where θ is the angle of accident impact, h is the height of the center of gravity of the of the combined person and bicycle masses and is estimated to be 1 0m In addition, an associated force due to gravity exists If we assume that there is an initial velocity at impact with the handlebar ($v_{impact1}$), the acceleration in the vertical direction can be solved after finding the velocity of impact with the ground ($v_{impact2}$) The energy equation associated with the second collision is.

$$\frac{1}{2} m_p {v_{impact1}}^2 + (m_b + m_p) g h = \frac{1}{2} (m_b + m_p) v_{impact2}^2 \tag{3}$$

Acceleration in the vertical direction can be calculated to be the following

$$a = \frac{v_{impact2}^2}{2h} \tag{4}$$

where velocity at impact can be calculated from the energy equation above Thus, in conclusion, the general force diagram leads to an equation given by the following·

$$F(h)\sin\theta - (m_b + m_p) g = \frac{(m_b + m_p) v_{impact2}^2}{2h} \tag{5}$$

Solving for F(h) yields the force associated with the accident Multiple forces were calculated by varying initial bicycle speeds and the angle of accident impact, θ The range of initial bicycle speeds was chosen based on the crash investigations These calculated forces were compared to the known compressive tolerance of the pediatric liver and spleen which have been previously measured to be 2649 Newtons and 785 Newtons, respectively (Sturtz, 1980)

Using a spring-mass-damper system, a novel handlebar was designed that, under pressures similar to those experienced during a crash, would retract and absorb the majority of the energy at impact In this design, the handlebar system would no longer be fixed upon collision Since the child remains in contact with the bar, the retracting system cannot return to the original position with the same force rate that caused it to initially retract The new bar would include a system to damp outward motion of the bar In addition to the retracting mechanism, the surface area of the handlebar ends would be increased to help distribute forces on the body

The mathematical system chosen to represent the new design was a spring mass damper system which can be described by the following equations

$$(m_p + m_b)\frac{d^2x}{dt^2} + c\frac{dx}{dt} + kx = F(t) \tag{6}$$

In the equation above, all variables (mass (m), acceleration ($d^2x/dt^2$), maximum compression (x), force at impact (F(t)), and velocity at impact (dx/dt)) are known except for k and c, the spring constant and viscous damping coefficient, respectively Therefore, iterating values for k will yield corresponding values for c

## RESULTS AND DESIGN

Six cases in which a child experienced serious abdominal injuries due to handlebar impact were analyzed (Table 1) Table 2 represents calculations of the force at impact (solution to Equation 5) from an average initial bicycle speed of 6 4 kph The force due to the initial impact of the child with the handlebar was calculated to be approximately 300 Newtons. Forces due to impact with the ground ranged from approximately 1200-7000 Newtons, with an average of 2355 Newtons. (6 4 kph initial bicycle speed) depending upon the angle at impact These calculations showed that the initial force of contact immediately following the drastic change in bicycle velocity is much less than the final impact with the ground. Thus the impact with the ground is the causal factor, not the initial contact force

The average impact force of 2355 Newtons is considerably larger that the 785 Newtons required to rupture the spleen Furthermore, the 2355 Newton value is comparable to the force at which the liver was found to rupture, 2649 Newtons Speeds exceeding 6 4 kph initial bicycle velocity (i e 8 0-12 9 kph for this study) have larger average force values than the liver rupture force tolerance

A standard industrial spring and damping grease (TAI Lubricants, Hockessin, Delaware) were chosen to provide the resistance and damping for the new prototype handlebar design, respectively The damping grease (NyoGel 774VL) had a dynamic viscosity of 106 N-s/m$^2$ This dynamic viscosity correlated with a spring constant of 1752 N/m or 10 lbs/in To aid in distributing the forces associated with impact, a protective cushion made of rubber-coated foam was added to the end of the bar, which increased the surface area at the end The prototype is pictured below (Figure 2)

The spring is fixed at both ends and "rides" along a shaft which supports the spring The shaft provides the safer handlebar system with dynamic stability Upon an impact force from the handlebar end, the handlebar would compress depending upon the magnitude of the impact force, and then release at a slower rate due to the damping effect of the grease For a 6 4 kph initial bicycle speed, the force at impact would reduce by approximately half from 2355 Newtons to 1177 Newtons Photos of the actual machined handlebar are shown in Figure 3

## DISCUSSION

A unique methodology was employed that translated research findings into product design. the mechanism of injury due to handlebar impact was delineated and a new handlebar design to mitigate these injuries was developed This design absorbs significant energy that otherwise would be transferred to the child's abdomen when impacting the handlebar

The prototype described in this report is a concept stage design only Further work would need to be done to completely characterize its performance and optimize the design for manufacturing and production For this design, the length of the spring was based on a set distance determined from the bicycles used in the actual cases. In manufacturing the system, there are several parameters that can be varied Changing the compression distance, and consequently the length of the spring, changes the spring constant An optimization of these parameters allows for the development of the least expensive, most effective unit Additional work needs to be done to assess the viability of a stiff spring (higher spring constant) versus a yielding spring (lower spring constant with more flexibility) with smaller and larger compression distances respectively In addition, the performance of the handlebar must be assessed for all angles of impact.

Although this design significantly reduced the forces transmitted to the abdomen (by half) in these types of crashes, the maximum force in the redesigned handlebar was calculated to be above the known tolerance of the spleen (approximately 800 Newtons) It is important to note that this tolerance level was determined from a single test in a 10-year-old child and as a result, may not be an exact value This data, however, represents the only information available and as a result, is the basis for the handlebar design In the next generation design, the forces should be further limited to a safety factor of at least 2 below the spleen tolerance, i e the maximum force should be limited to 400 Newtons This could be achieved simply by using a different combination of spring and damping grease

In designing a device that is to be implemented on all bicycles, it is also important to consider price and practicality The actual shape of the handlebar can only be changed such that the functional purpose is not altered. If the children cannot maneuver with the same ease, then they are more likely to have accidents In addition, the device must be aesthetically appealing to children in the target age group During investigation of the crashes described herein, it was determined that children often remove safety features on bicycles to increase the maneuverability or aesthetics If they feel that the handlebar makes the bike look strange or uncomfortable, they will be less likely to purchase it. Prior to determining a final handlebar design, a focus group of children should be conducted, testing the aesthetics of possible handlebar systems In particular, the children's input should be considered in developing the mold for the rubberized foam padding that would be placed on the handlebar ends

## CONCLUSIONS

A unique methodology of translating research findings into product design produced a retractable handlebar consisting of a spring-mass-damper system that, under pressures similar to those experienced during a crash, retracts and absorbs the majority of energy transferred to a child's abdomen at impact This prototype was designed to reduce the forces at impact by approximately 50% in a collision similar to those that have previously caused injury This design will be instrumental in reducing the severity of abdominal injuries experienced by young cyclists

## ACKNOWLEDGEMENTS

This work was funded by Agency for Health Care Quality (formerly known as Agency for Healthcare Policy and Research) Grant number 5 U01 HD32828 as part of the Emergency Medical Services for Children Program The authors would like to acknowledge Dynamic

Science Inc and the United States Consumer Product Safety Commission who performed the crash investigations, Rajiv Menon, PhD, for his advice during the prototype design. and Joe Pilli for his advice and assistance in the machining of the prototype

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**Table 1**-Case Summaries

| Case # | Child age (yrs) | Child mass (kg) | Handlebar turn radius(deg) | Bicycle Weight (kg) | Injury |
|---|---|---|---|---|---|
| 1 | 14 | 50 3 | 90 | 12 3 | Severed kidney, bruised pancreas |
| 2 | 11 | 49 8 | 360 | 12 9 | Splenic laceration |
| 3 | 7 | 31.7 | 360 | 14 7 | Splenic laceration |
| 4 | 8 | 27 0 | 90<r<180 | 12 9 | Liver laceration |
| 5 | 11 | 43 0 | 360 | 10 9 | Splenic laceration |
| 6 | 6 | 25 0 | 360 | Unknown | Liver laceration |

**Table 2** - Force Calculations for 6 4 kph (1 8 m/s) Initial Bicycle Speed

| $m_b$ (kg) | $m_p$ (kg) | $v_b$ (m/s) | $v_{impact2}$ (m/s) | θ (degrees) | Force at impact (N) |
|---|---|---|---|---|---|
| 12 6 | 44 1 | 1 8 | 4 7 | 10 | 6811 |
| 12 6 | 44 1 | 1 8 | 4 7 | 20 | 3458 |
| 12 6 | 44 1 | 1 8 | 4 7 | 30 | 2366 |
| 12 6 | 44 1 | 1 8 | 4 7 | 40 | 1840 |
| 12 6 | 44.1 | 1 8 | 4 7 | 50 | 1544 |
| 12.6 | 44 1 | 1 8 | 4 7 | 60 | 1366 |
| 12 6 | 44 1 | 1.8 | 4 7 | 70 | 1259 |
| 12 6 | 44 1 | 1 8 | 4 7 | 80 | 1201 |
| 12 6 | 44 1 | 1 8 | 4 7 | 90 | 1183 |

Figure 1

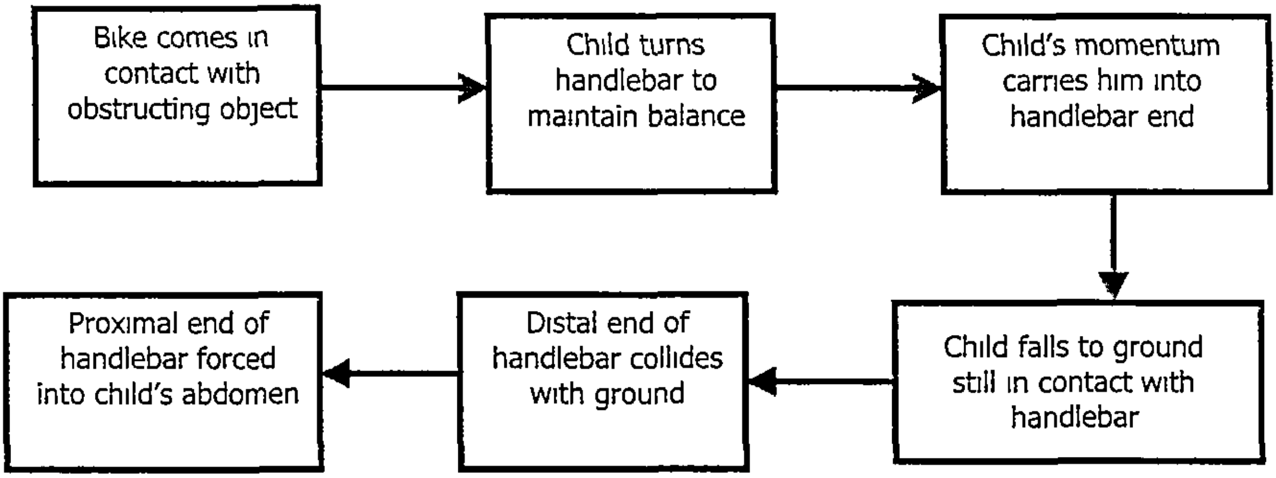
Bike comes in contact with obstructing object
Child turns handlebar to maintain balance
Child's momentum carries him into handlebar end
Child falls to ground still in contact with handlebar
Distal end of handlebar collides with ground
Proximal end of handlebar forced into child's abdomen

Figure 2

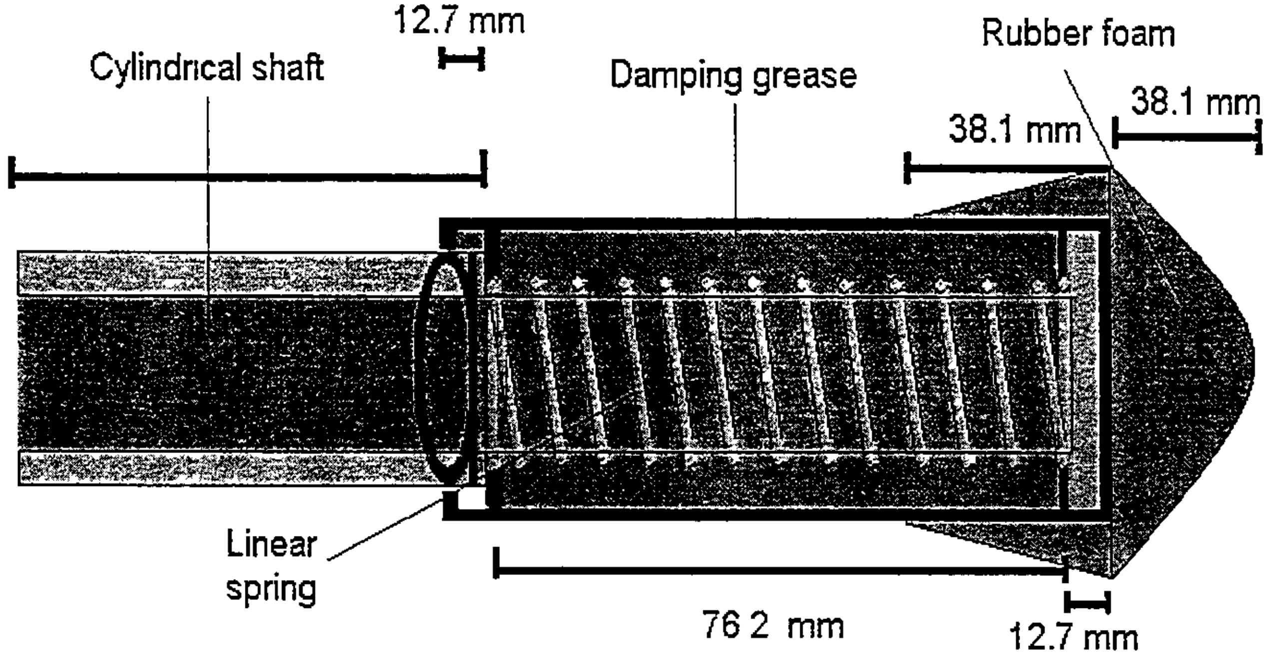
12.7 mm
Cylindrical shaft
Damping grease
Rubber foam
38.1 mm
38.1 mm
Linear
spring
76 2 mm
12.7 mm

Figure 3

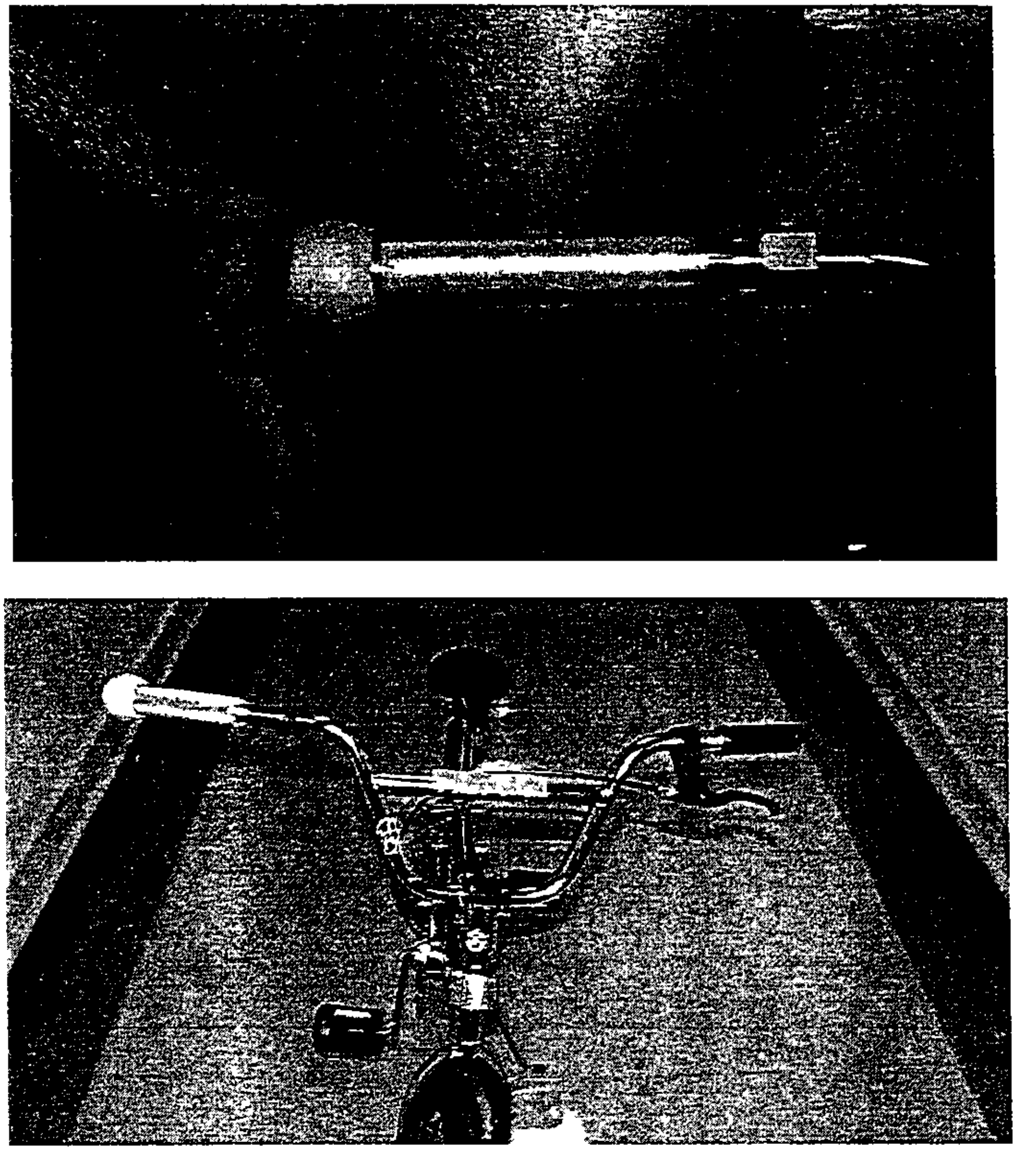

Figure captions

**Figure 1** – Schematic of injury event unfolding

**Figure 2** - Theoretical prototype of redesigned handlebar The design consists of a linear spring on a cylindrical shaft surrounded by damping grease Upon impact, the spring would compress and then release at a slower rate due to the damping effect of the grease.

**Figure 3** – Actual photos of redesigned handlebar