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Review of Pediatric Head and Neck Injury: Implications for Helmet Standards

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Summary of a conference held at The Children's Hospital of Philadelphia, Philadelphia, PA on March 31, 2003

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Overview

Motorsports--the use of off-road motorcycles such as dirt bikes or minibikes — have been increasing in popularity in recent years. Although the tracks for motorsports races are designed to reduce the risk of injury, many people, including children, do motorsports both on and off these tracks in unstructured, potentially hazardous riding situations. The increasing popularity of motorsports, consequently, has boosted numbers of injuries linked to wheeled off-road motor vehicles. Between 1997 and 2002, the number of these injuries nearly tripled in number, according to the Consumer Product Safety Commission (CPSC).

Motocross racing is a rapidly expanding example of children's motorsports activities. Many of the injuries linked to motorsports occur in children less than 16 years of age. According to CPSC, between 1994 and 1996, about 40,000 injuries related to 2-wheeled motorized off-road cycles were treated in emergency departments each year and more than one-quarter were sustained by children younger than 15 years of age. From 1990 through the first quarter of 1995, at least 50 reports of deaths related to minibike and trailcycle use were reported to the CPSC, and nearly half were in children 16 years of age or younger.

According to Dr. Susan Baker of Johns Hopkins University, 8 percent of all injuries linked to motorsports in children 12 years of age and younger are head injuries. Despite this CPSC data, there currently are no helmets or helmet standards specifically designed to protect children who do motorsports. These children, many of whom are as young as 6 years of age, tend to use adult motorcycle helmets, which are ill-fitting and heavy, and do not take into account children's unique anatomy.

On March 31, 2003, the Snell Memorial Foundation convened a meeting held at The Children's Hospital of Philadelphia. Dr. Hal Fenner opened up the meeting, the purpose of which was to review what is known about pediatric head and neck injury relevant to protective helmet design so as to determine what needs to be considered when developing a helmet standard for children who pursue motorsports. A secondary purpose of the conference was to identify critical issues requiring more information, so as to direct future research in pediatric head protection. Four hours of presentations by experts in pediatric head or neck injuries or helmet design were followed by about two hours of discussion. This document is a summary of the conference, particularly the discussion portion during which specific recommendations were made. This summary is divided up into the following sections:

- Differences in injury patterns between children and adults;
- Anthropometric and biomechanical differences between children and adults;
- Pediatric motorsports helmet design constraints;
- Research needs; and
- A summary of the recommendations for the development of standards for pediatric motorsports helmets and helmet testing.

Differences in Injury Patterns Between Children and Adults

Animal studies presented by Dr. Ann-Christine Duhaime and Dr. Susan Margulies reveal that age affects the response and recovery of the brain to a focal impact and to rotational load. In Dr. Duhaime's study of piglets, the degree of damage, as measured by brain cell death, increased with the animals' age. In response to the same focal impact, piglets equivalent in age to human infants experienced the least amount of damage one week after injury, and piglets equivalent to 11-13-year old humans had the most damage. The oldest piglets were also more prone to late swelling, from such a brain injury, compared to younger piglets. In Dr. Margulies' pig study of diffuse brain injury, three times more axons were damaged in infant piglets within 6 hours after injury than in adult pigs given the same non-impact rotational load.

These studies suggest that older children may be more prone to focal impact damage than younger children, and that helmet standards for older children may need to be different than that for younger children or for adults. But Drs. Duhaime and Margulies pointed out that more research needs to be done to ensure their animal findings are relevant to children.

When discussing whether helmet standards for motorsports in children should consider protection from mild traumatic brain injury (concussions), one participant noted a recent National Academy of Sciences report on soccer and head injuries in children. (Patlak and Joy, 2002) This report concluded that children are more likely than adults to suffer severe consequences from concussions. These consequences include second impact syndrome, which is often fatal or results in learning impairment.

Dr. Randal Ching pointed out that of all pediatric injuries, spine injuries are among the most severe and most of these injuries occur in the cervical spine. Other participants noted that this has relevance to helmet standards as cervical spine injuries may result from head impact events that cause injury, and ill-fitting helmets may exacerbate risk of these injuries.

Anthropometric and Biomechanical Differences Between Children and Adults

There are a number of size, shape and biomechanical differences between children and adults that are relevant to the development of helmet standards for pediatric motorsports. Dr. Kathleen Klinich presented University of Michigan Transportation Research Institute (UMTRI) data that revealed that the head size of a child grows rapidly between ages 0 and 4 years, after which it grows more gradually. By age 4, the size of a child's head (as indicated by head breadth, depth and circumference) is 90% that of an adult and by age 12 it is 95% of adult size. It is not until age 20 that the bone plates of the skull fully close.

An important consideration in helmet standard development that Mr. Edward Becker pointed out is that the facial structure of children is vastly different from that of adults. Children's heads are smaller in vertical height than adults'. Consequently, adult-sized helmets can obscure children's vision and not fit properly on their heads. Mr. Becker noted that in a small child, the adult-sized motorcycle helmet may actually rest on his shoulders and he may not be able to get his head deeply enough into the helmet to even test the crown fit. Even older children may find that the chinstrap will not secure the helmet properly as chinstrap anchor points are placed to satisfy adult anatomy. They are likely to be too low and too far forward for children.

The brain and skull of a child have different biomechanical properties than adults'. The greater water content in a child's brain makes it stiffer than that of an adult, noted Dr. Margulies. In addition, her research has found that skull stiffness increases with age. Based on her studies in pigs and young children, she concluded that the infant's less stiff skull properties are likely to increase the magnitude of intracranial strains that occur during head injuries involving impact. But she noted that whether that is also true for older children is not known.

The neck, in contrast to the head, is only 75% of adult size at age 4 and 85% of adult size by age 12, according to UMTRI data. The head-volume to neck-area ratio at age 12 is still greater than what is seen for adults. In addition, Dr. Kristy Arbogast noted that the neck muscles of children are weaker than adults, and children's neck ligaments can stretch more. She also pointed out that children bend their necks at higher vertebral levels than adults, and their vertebral joints are flatter so they don't restrict forward motion as much as in adults. Children's spinal columns also have more cartilage and less bone, Dr. Arbogast added.

Baboon and goat animal model data generated by Dr. Ching and Dr. Frank Pintar suggest that children's necks require less force to fail in tension, and compression and experience lower bending stresses than adults. In these animals, neck stiffness gradually increases with age. The same is likely to be true in children and influences the neck injuries they experience from a head impact. One participant noted that, unlike adults, children can experience spinal cord injury without suffering vertebral fractures due to ligament laxity and high cartilage content.

Design Constraints

A number of design constraints for motorsports helmets for children were discussed at the conference. These included the need to lower the weight and reduce the size of motorsports helmets for children so as to lower their risk of neck injury, not restrict their vision, and improve ease of use. Also discussed was whether motorsports helmets for children should offer protection for both high and low impact situations, and for multiple as well as single impacts. In addition, the age-range for which a helmet standard should be developed was debated, as well as how effective at reducing injury a helmet design needs to be.

Dr. Daniel Thomas opened the afternoon discussion by noting that no helmet offers 100 percent protection from head injury. He referred to Dr. Fred Rivara's presentation of data from two well-designed studies that found bike helmets lower the risk of brain injury by 88 percent. This figure is something to strive for with a motorsports helmet, but Dr. Thomas noted that even a helmet that offers 50 percent protection from injury would be of value. Using data from several studies, Dr. Rivara presented a chart of bicycle helmet effectiveness that is reproduced in Appendix 1.

Although children younger than 6 years of age participate in motorsports, many of the speakers and participants argued for not developing a helmet standard for such young children. Some participants thought the sport was inherently more dangerous in younger children and suggested these young children be restricted from motorsport activities. Others expressed concern that motorsports are dangerous for even older children and a pediatric helmet standard that includes these younger ages should not be developed because it might encourage parents to allow their children to participate. One participant noted a 2000 policy statement by the American Academy of Pediatrics (AAP, 2000) that states "Off-road vehicles are particularly dangerous for children younger than 16 years who may have immature judgment and motor skills. Children who are not licensed to drive a car should not be allowed to operate off-road vehicles. "

But Snell participants noted that regardless of AAP's stance on off-road vehicle use, motorsports activities are common among children, who should be properly protected with suitable helmets. Dr. Baker noted that the almost all injuries from off-road 2-wheel motorcycles in children, according to CPSC 1997-2001 data, were in those aged 6 and older. Dr. Jondy Cohen's pilot study of motocross competitors also found no injuries in children aged 4 to 6. These observations probably reflect a greater prevalence of motorsports in older, as opposed to younger children, rather than a reduced incidence rate among the youngest participants. Once again, these data underscore the notion that older children might be an appropriate target age for a helmet standard.

Based on the discussion at the conference, Snell participants decided afterwards to focus on developing a pediatric motorsports helmet standard for children 6 years and older. For that standard, it was decided by conference participants that there was not enough information on how children differ from adults to justify changing the 300g acceleration limit that is currently the standard for adult motorcycle helmets. After the conference, one participant raised the issue that while experimental data do not readily exist to support lowering the G threshold; some adults wearing approved 300g helmets receive head injuries. Army aviation helmets are designed to limit head from acceleration to 175g and have performed remarkably well thus suggesting the possibility that a lower threshold may provide better protection.

The tracks for motorsports are soft surfaces designed to cushion falls. But several participants pointed out that children frequently practice off the track where they can hit their heads on rocks and other hard surfaces. For this reason, there was consensus that a motorsports helmet standard be designed to protect against a head impact with a hard surface.

Some participants pointed out that a helmet designed to offer protection from a single impact situation may differ from that required to protect against multiple impact situations. It was suggested that any helmet standard that is developed for motorsports should specify in the label whether it is for single-impact or multiple-impact protection.

There was some discussion as to whether a motorsports helmet should protect from concussion as well as permanent brain injury. No helmet currently is designed to offer protection from concussion. Some participants thought repeated concussions in children were problematic and helmets should offer protection from mild traumatic brain injury. But other participants pointed out that low impact (resulting in concussion) and high impact (resulting in permanent brain injury) protection may be incompatible in a single helmet of a reasonable size and mass. Most agreed that the helmets must protect at least against high impact. It was suggested that well-designed epidemiological studies would reveal where the injuries are and provide guidance for the area of focus of helmet standards.

To offer more protection from mild traumatic brain injuries, the padding of helmets must be made thicker. To keep the helmet the same size and weight, therefore, the outer shell must be made thinner. But a thinner shell has less space to provide energy attenuation and therefore has lower protective capability from permanent brain injuries. A few participants suggested this trade-off might be overcome with innovative materials. But others questioned the feasibility of this, especially whether the use of such materials is likely to result in a helmet that is too expensive for the average consumer.

Another problem with increasing the padding thickness in helmets is that the thicker the padding, the greater the likelihood of neck injuries, as modeling studies of adult head and neck injuries at Duke University suggest. Their studies conclude the presence of head constraint can pocket the head and decrease the ability of the neck to escape the moving torso, thereby predisposing the neck to injury. Thus, injury prevention devices and environments (helmets, car interiors, crash mats, etc.) while providing protection to the head should be designed to consider head and neck motion. Dr. Michael Prange stressed that helmets be designed to facilitate head and neck motion and cautioned that engineers be wary of adding thick padding to their helmet designs.

The issue of head/neck restraint is relevant for car-type motorsports, such as Go-Karts and Quarter Midgets, as well. When no restraint system is worn, the helmet requirements would be similar to bike-based motorsports. However in some car-based motorsports, a restraint (a harness system) is used. With this system, designs such as the HANS that are used in adult car racing events to stabilize the head and neck complex may be appropriate for children.

Some participants at the conference recommended that surface friction and head pocketing be considered when developing a pediatric motorsports helmet standard. Friction levels are already specified in European helmet standards. But Dr. Thomas noted that current friction testing methods use helmets attached tightly to head forms — a situation that does not reflect the loose coupling of the helmet to the head that often occurs. Also inspection of helmets involved in impact events found that despite melted expanded polystyrofoam and nylon indicating large frictional forces, there were no neck injuries linked to these impact events in this study. (Rivara, Thompson and Thompson, 1996) Dr. Prange presented data from drop test experiments that demonstrated a reduction in head and neck injury metrics with a decrease of helmet surface friction. The participants emphasized that the issue of friction and head pocketing be a focus of future research.

Most of the discussion centered on how to lower the size and weight of a helmet for pediatric motorsports without compromising the degree of protection the helmet gives from brain injury. Other parameters such as liner thickness, liner density, and shell material can influence the relationship between helmet mass and head injury protection. The typical motorcycle helmet mass is 1.5kg and the typical bicycle helmet mass is 0.3kg. User fatigue and acceptance limit the weight of helmets sold in the marketplace.

Current helmet weights have not been found to be a significant risk for adults. Based on available data, Dr. Prange concluded that a helmet mass of 2. 0 kg is within non-injurious limits for adults and does not cause user fatigue in this population. But such a helmet may be more than half the head weight of some of the children who wear them for motorsports, pointed out Mr. Becker. Most participants agreed that this mass limit should be set lower for children, who are not only smaller, but have weaker neck structures.

Several participants expressed concern that a helmet that is too heavy for a child, while perhaps protecting him from head injury, will make him more prone to a neck injury. But the effect of helmet weight on neck injury may vary depending on the type of impact a child receives. Dr. Thomas Gennarelli and colleagues have used bioengineering principles and anthropometric data to develop a model that predicts the likelihood of neck and head injuries for given impacts. In his presentation, Dr. Gennarelli showed that for children of all ages who experience an impact to the body, as the weight of the helmet goes up, so does the neck shear force and bending moment, and therefore the likelihood of sustaining a neck injury increases. But for children who experience an accidental fall to the ground head first (axial neck force), the heavier the helmet the less neck axial force and thus the less likelihood of sustaining a neck injury.

Other studies reveal rhesus and baboons exposed to negative and positive impact acceleration applied to the torso results in tension failure of the head-neck system as the head is rotated. (Thomas and Jessop, 1983; Thomas and Jessop, 1986; Clarke, et al., 1972) The neuropathological finding in the rhesus experiments has been published. (Unterharnscheidt, 1986) The ultimate goal in the design of a helmet for children, Dr. Gennarelli stated, would be to reduce the helmet weight yet increase the energy absorbing ability at the same time.

Dr. Ching was asked after the conference to use his baboon and Dr. Pintar's goat data of age-related stiffness of the osteoligamentous cervical spine to scale the assumed reasonable maximum helmet weight of 2kg for adults down to weights appropriate for various pediatric age categories. After performing the necessary calculations on the data, Dr. Ching estimated that an appropriate helmet weight range for a child aged 6 years is between 0. 91 and 1. 17kg and for a 12-year-old child is between 1.24 and 1. 6kg. (See Appendix 2.) Dr. Pintar also used the neck muscle cross-sectional area data from Dr. Tokio Kasai's study of 150 human children age 5-20 years old (Yoganandan et al, 2002) to scale down an appropriate helmet weight for children of various ages and derived figures similar to that of Dr. Ching's.

But Dr. Ching noted that his rudimentary analysis is based on numerous assumptions and has limitations. First, it assumes that the 2 kg weight limit suggested by Dr. Prange is reasonable for adults. Second, it does not take into consideration how neck muscle loads or strengths may vary with age and affect stiffness. Third, it assumes equal weighting between directions of loading (tension, compression, and bending). Fourth, the data on which the analysis is partially based do not account for species- or gender-related differences.

One participant pointed out that making a helmet smaller, so that it conformed more to the size and shape of a child's head, might reduce the weight of the helmet sufficiently without compromising its energy attenuation capability. Others suggested using novel materials to lighten the weight of helmets without compromising their ability to protect the head. But novel materials are typically too expensive to be practical. Most participants acknowledged it may not be possible to lower the weight of a helmet designed for child motorsports without also lowering the energy requirements for testing, and thus the protective ability of the helmet. Ease of use (fatigue potential and ease of taking on and off and fitting properly) and cost are also important considerations for motorsports helmet design.

A major practical consideration that emerged during the discussion portion of the conference is that currently there are no testing head forms that approximate a child's head. Without such head forms, a helmet designer or compliance engineer cannot adequately assess how a helmet will affect a child's vision, stay on during an impact, let alone how well it will protect the child from head injury.

There was strong agreement that a pediatric head form for helmet testing be developed based on UMTRI anthropometric data. In addition, it was recommended that testing of helmets for children include roll-off testing and testing to ensure the helmet fits close enough to the child's head.

Research Needs

During the discussion portion of the conference a number of information gaps were noted in regards to pediatric motorsports, including the need for better surveillance and follow up of motorsports injuries, more modeling and animal studies, more efforts to use crash test data to validate models, and a better understanding of injury mechanisms. Several participants pointed out the need for better surveillance of injuries in children who do motorsports. Such surveillance data should detail the types of injuries sustained, including concussions, the ages of the children, and outcomes. This data should also be related to the total number of children who do motorsports during a certain period of time so as to calculate incidence and prevalence figures. To obtain accurate information, it must be population based. It was also suggested that researchers conduct well-controlled studies to explore whether some injuries are more common in motorsports in specific age categories, so development of prevention measures can be prioritized appropriately.

Although theoretically, children who do motorsports might seem prone to neck injuries from head impacts with helmets that are too heavy, there is a lack of data on neck injuries in such children. It may be difficult to assess this, however, as most neck injuries in children are ligamentous in nature as opposed to cervical fractures. The symptoms of such neck injuries tend to be delayed, and may not be reported when an initial accident report is made, one participant pointed out.

It was also suggested that there be more studies on how retention system performance of the helmet affects head and neck injuries. Such retention performance is an important consideration in helmet design, yet there is a lack of information on what is the most appropriate retention system performance that will cause the least injury to the head and neck during an impact situation.

Participants agreed that animal studies and modeling are critical to the development of injury criteria for helmets and should be pursued. It was suggested that researchers consider indirect as well as direct impacts in their modeling studies. Some criteria that may emerge from these studies (such as brain strain rate) may also require modeling to be employed to test for helmet compliance with these criteria. (See below.)

Several participants also suggested that the validity of models be tested with data from actual crashes. Crash reconstruction studies can also identify the most common (or most injurious) loading modes. Because the data indicate that head and neck response varies by loading mode, these studies can suggest appropriate loading requirements for helmet standards and testing.

Dr. Albert King suggested in his presentation that there be more studies to better elucidate brain injury mechanisms during head impacts so as to improve helmet design and testing criteria. He pointed out that it is traditionally assumed that angular acceleration is a cause of diffuse brain injury upon impact. But helmets do not directly alter angular acceleration significantly and yet still offer protection from brain injury. This suggests other factor(s) play a primary role in causing brain injury upon impact. Dr. King's modeling studies, which use real data from football collisions, indicate that brain strain rate is a better predictor of head injury than acceleration.

If his findings are confirmed, Dr. King suggested modifying tolerance levels based on brain response parameters and changing helmet standards accordingly. Testing methods will also need to use new head forms that yield values of response parameters rather than those of input parameters. Alternatively, one could supplement helmet tests with computer models. For pediatric helmets, this would require researchers to develop computer models of children's heads for a range of different ages and to establish the tolerance levels of children's brains.

All participants agreed that to close necessary information gaps, researchers should pursue the studies needed and indicated in the previous section. But in the meantime, it was suggested that Snell develop a preliminary pediatric motorsports helmet standard based on the information available to date. The standard should then be modified, if necessary, once more information is acquired.

Participants also recommended that once a pediatric motorsports helmet standard is developed, researchers conduct a follow-up study to assess if the standard is sufficiently effective in reducing the head and neck injuries of children in crash situations. Such a prospective study could be undertaken using organized motorsports competitions. This study would be most valuable. Although it would require several years and large financial resources to conduct, it would offer the best value for an epidemiologic study of this issue.

Summary of Recommendations

From the conference the following recommendations were made regarding pediatric motorsports helmet standard development and testing:

1) Develop a motorsports helmet standard for children 6 years of age and older.*
2) Design a pediatric motorsports helmet standard to include protection from head impacts with a hard surface.
3) In the labeling of a motorsports helmet standard, specify that it is to protect against permanent brain injury from a single impact event.
4) Consider surface friction and head pocketing when developing a pediatric motorsports helmet standard.
5) Lower the mass limit for helmets designed for children using the scaling approach recommended in the report.
6) Consider pediatric size constraints when developing a helmet standard for children.
7) Consider ease of use (fatigue potential and ease of taking the helmet on and off and fitting it properly to the head) as well as cost in a motorsports helmet design.
8) Keep the 300g acceleration limit in a pediatric motorsports helmet standard until more data suggest otherwise.
9) Develop a pediatric head form for helmet testing based on UMTRI anthropometric data.
10) Include roll-off testing and testing to ensure the helmet fits close enough to the head in the testing of helmets for children.
11) Conduct better surveillance of motorsports injuries in children.

12) Conduct more modeling and animal studies that can indicate injury criteria for the brain in impact situations akin to motorsports-like events. The validity of models should be tested with data from actual crashes.

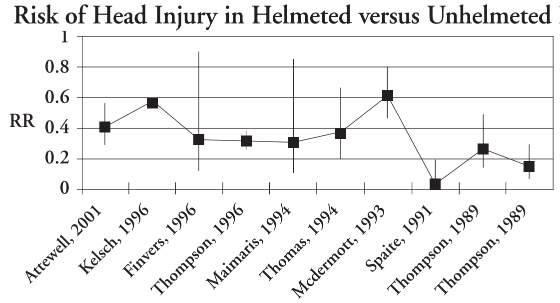
13) Develop a preliminary pediatric motorsports helmet standard based on the information available to date. This standard should then be modified, if necessary, once more information is acquired.

14) Once a pediatric motorsports helmet standard is developed, conduct a follow-up study to determine the effectiveness of helmets that meet the standard to prevent head and neck injuries in children who use them during motorsports competitions.

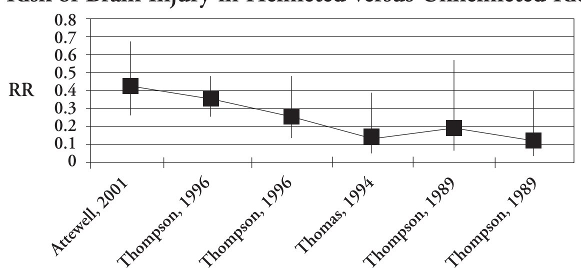
* *There was not consensus on this issue. Some participants expressed concern that motorsports are dangerous for children and a pediatric helmet standard that includes younger ages should not be developed because it might encourage parents to allow their children to participate.*

Appendix 1: Previous Rearch on Bicycle Helmet Effectiveness

Risk of Head Injury in Helmeted versus Unhelmeted Riders



Risk of Brain Injury in Helmeted versus Unhelmeted Riders



Appendix 2: Scaling Helmet Weight from the Adult to the Child

Randal P. Ching, Ph.D., University of Washington Applied Biomechanics Laboratory

Although limitations abound, it is possible to scale the acceptable weight for a child's helmet based on the scaling relationships developed by the University of Washington (UW) and Medical College of Wisconsin (MCW) and the analysis presented by the group at Duke University. If we accept the premise that a reasonable maximum helmet weight for adults is 2kg (Prange, 2003) , then maximum helmet weights for children could be obtained by applying scaling relationships to this adult value to yield corresponding child limits. Rather than using scaling parameters based on tolerance (failure) data, it would be more appropriate to apply functional metrics (e. g. , stiffness, modulus, range of motion) instead. For example, the following table lists the scaling relationships between the adult (100 percent or 1.0) and various age groups based on measured stiffness properties in both the baboon and goat models.

Table 1: Stiffness scaling ratios.

Age Group (years)	UW (Baboon)			MCW (Goat) (Hilker, 2002)		Mean (± 1S.D.)
	Tension	Compression	Bending	Tension	Bending	
1	0.42	0.29	0.19	0.17	0.11	0.24 (±.12)
3	0.47	0.38	0.28	0.23	0.15	0.30 (±.13)
6	0.56	0.51	0.41	0.54	0.57	0.52 (±.06)
12	0.71	0.72	0.64	0.85	0.62	0.71 (±.09)
Adult	1.0	1.0	1.0	1.0	1.0	1.0

If we compute the means and standard deviations for these ratios by age group, we can establish a scaling corridor (± 1 s. d.) for each age group based on stiffness. By multiplying the high (mean + 1 s. d.) and low (mean – 1 s. d.) values by the 2kg limit for adults, we can then estimate a range for child helmet weight limits. These weight ranges are listed in the following table.

Table 2: Helmet weight limits based on stiffness scaling ratios.

Age Group (years)	Lower Limit (kg)	Higher Limit (kg.)
1	0.23	0.72
3	0.35	0.86
6	0.91	1.17
12	1.24	1.60
Adult	—	—

Although this rudimentary analysis enables us to establish helmet weight limits for children, it is fraught with assumptions and limitations. First, it presumes that the 2 kg weight limit presented by the Duke group is a reasonable limit for adults. Second, it does not take into consideration how muscle forces or strength may vary with age and simply uses the age-related stiffness of the osteoligamentous cervical spine to perform the scaling. Third, it assumes equal weighting between directions of loading (tension, compression, and bending) and between animal models. Fourth, the UW scaling values were obtained using a single gender (all males), whereas the MCW values were based on a mixed gender population.

In sum, a means to compute helmet weight limits using the scaling relationships established by the UW and MCW groups has been demonstrated. "Are these limits reasonable?" and "should they be put forward?" are questions to be decided by the entire group attending the workshop. Further complicating the issue is whether or not any limits should be reported for the lower age ranges (less than 6 years old). Here again, this is an issue that should be decided by the whole group, not just one member.

Appendix 3: List of Participants

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Appendix 4: Agenda

Review of Pediatric Head and Neck Injury

8:30 a.m.	**Introduction** Hal Fenner – *Welcome & Introductions*
8:40 a.m.	**Clinical Medicine and Epidemiology** Susan Baker – *Overview of the Broad Epidemiology* Fred Rivara – *Review of Bicycle Helmet Literature and Its Applications to Other Impacts* Jondy Cohen – *Motocross Injuries* Ann-Christine Duhaime – *Injury and Recovery in Children* Tom Genarelli – *Helmets in Relation to Neck Injuries*
9:55 a.m.	**Anthropometry** Kathleen Klinich – *Anthropometry and Head/Neck Impacts* Kristy Arbogast –*Developmental Anthropometry of the Neck and Neck Injuries in the Automotive Environment*
10:25 a.m.	**Break**
10:45 a.m.	**Biomechanics** Randy Ching/Frank Pintar – *Tolerance of Pediatric Neck Compared to Adults* Susan Margulies – *Pediatric Brain/Skull Tolerance* Michael Prange – *Adult Neck Injuries and Helmets*
11:45 a.m.	**Standards** Albert King – *Experimental Basis of the Wayne State Curve and Its Relationship to Helmet Standards* John Melvin – *Effectiveness of Neck Restraint from Race Car Experience, Role of Scaling*
12:15 p.m.	**Lunch**
1:15 p.m.	**Edward Becker - Review of Test Standards and Methods, Materials of Helmets**
1:30 p.m.	**Discussion** All Participants – *Issues Raised During Morning Workshop*
3:15 p.m.	**Summary of Discussion**
4:30 p.m.	**Adjourn**

Appendix 5: References

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