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PREVENTION OF ACCIDENTAL CHILDHOOD STRANGULATION

A CLINICAL STUDY

RYAN R. STEVENS, MD
DENVER, COLORADO

GEOFFREY A. LANE, MD
DENVER, COLORADO

SCOTT M. MILKOVICH, PHD
LOMBARD, ILLINOIS

DANIEL STOOL
LOMBARD, ILLINOIS

GENE RIDER
LOMBARD, ILLINOIS

SYLVAN E. STOOL, MD
DENVER, COLORADO

Accidental strangulation is a preventable problem, and there is limited scientific understanding of its mechanism in children. If the amount of external pressure that occludes the airway can be determined, design changes may be made to allow for production of household objects that would break apart at safe pressure levels. A force gauge was applied to the suprahyoid region in 90 children under standardized anesthesia. Three blinded observers performed the study. The anesthesiologist maintained the airway and used a stethoscope to auscultate for breath sounds and monitor the CO_2 curves to evaluate obstruction. The recorder noted the numbers from the gauge. A single observer applied the force gauge. Age was the most significant variable in occluding the airway. Obstruction appears to occur at the level of the larynx. Increased knowledge regarding the external pressure required for airway occlusion would allow for the design and manufacture of products with a reduced potential for accidental strangulation.

KEY WORDS — accident, airway obstruction, injury, neck, prevention.

INTRODUCTION

The leading cause of death in children is accidental trauma. Asphyxia was the most common cause of infant deaths reported by the National Center for Health Statistics in 1997 (Fig 1).[1] The annual incidence of unintentional pediatric asphyxia deaths is 11.0 per 100,000 infants in the United States. Ropes or cords were involved in 24% of asphyxias in the United States (choking episodes involved 9% of asphyxias)[2] and in 17% of asphyxias in Wales and England.[3] The incidence of accidental fatal asphyxia has not decreased significantly since 1962, despite US federal regulation changes. In fact, the US National Center for Health Statistics reported that the incidence of asphyxia in infants in 1995 was 10% higher than that from 1985.[1] There is a surprising lack of clinical research on childhood accident prevention. A common scenario in the United States involves window-covering cords in which infants become entangled while sleeping and from which toddlers become suspended while playing on or jumping from furniture.

Hanging is caused by constriction of the neck as a result of suspension in such a manner that the weight of all or a part of the body pulls on the ligature.[4] These forces constrict the airway in a vector directed superior and posterior (Fig 2). Suspension occurs above the larynx but below the angle of the jaw, as noted in 80% of adult hangings.[4] Jaw projection prevents superior displacement of the ligature.

There is very little information regarding the internal mechanisms that result in this unfortunate event. Airway obstruction in hanging is currently believed to occur as the base of the tongue is pushed against the posterior wall and the epiglottis folds over the larynx.[4] The arteries and veins have a major role in strangulation. Adult autopsy studies performed by Brouardel[5] in France in the 19th century showed that the amount of mass needed to occlude the carotid

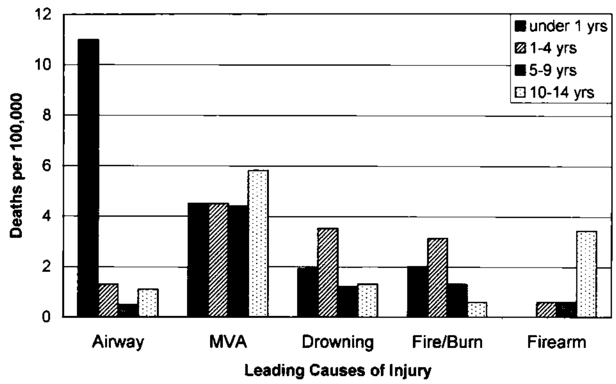

Fig 1. Death rates for leading causes of injury among children under 15 years of age in United States in 1995. (Data from National Center for Health Statistics.[1])

From the Departments of Otolaryngology (Stevens, S. E. Stool) and Anesthesia (Lane), Children's Hospital, University of Colorado Health Sciences Center, Denver, Colorado.

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CORRESPONDENCE — Ryan R. Stevens, MD, Children's Hospital, University of Colorado Health Sciences Center, 1056 E 19th Ave, B455, Denver, CO 80218.

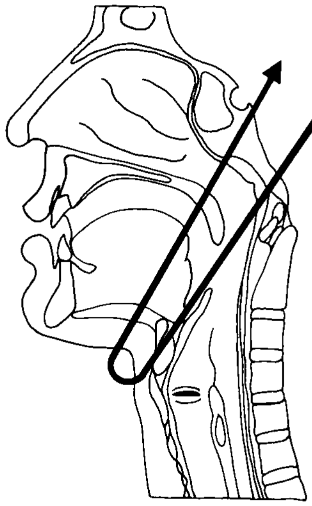

Fig 2. Sagittal view of head and neck with representative loop demonstrating location of suspension hanging. (Modified with permission from McGee JP, Vender JS. Nonintubation management of the airway: mask ventilation. In: Benumof JL, ed. Airway management: principles and practice. St Louis, Mo: Mosby–Year Book, 1995:228-54.)

artery was 5 kg, the internal jugular vein 2 kg, and the trachea 15 kg.

In adults, accidental strangulation or hanging is far less common than homicide or suicide, which usually involves complete suspension. Judicial hanging involves a drop at least equal to the height of the person to result in an odontoid fracture.

The most common scenario in young children is partial hanging. Partial hanging occurs when a portion of the body is supported (ie, kneeling or standing). In partial hanging, tension applied to the neck may occlude the airway but not the artery, resulting in asphyxia. Regardless of whether it is partial or full suspension, the forces are similar on the neck.

Accidental strangulation is a preventable problem with limited scientific understanding in children. Where does obstruction occur? How much force does it take to significantly obstruct the airway? If this information was known, many of these events could be prevented by designing products to reduce the risk of strangulation.

As part of a study regarding maintenance of the airway in small children, observations were made that led to this study of suspension. Our present study was designed to evaluate the amount of force applied to the hyoid region of the neck needed to occlude the airway. Additional factors of weight, age, and sex were evaluated for any correlation. Tooth eruption, tonsil size, and placement of an oral airway were evaluated to determine the internal site of obstruction (hanging) and were verified by flexible endoscopy.

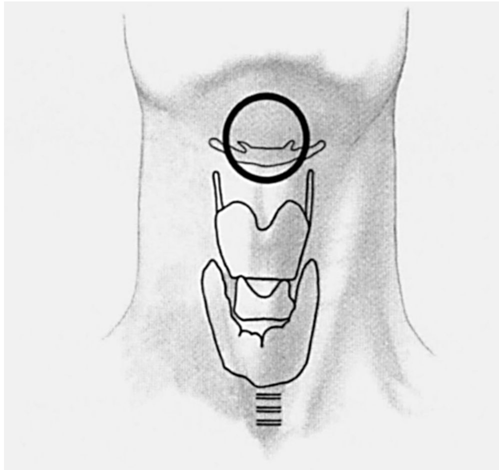

Fig 3. Demonstration of position of force gauge on neck with landmarks for reference. (Modified with permission from Silver CE. Surgical anatomy. In: Silver CE, Ferlito A, eds. Surgery for cancer of the larynx and related structures. Philadelphia, Pa: WB Saunders, 1996:13-26.)

MATERIALS AND METHODS

This study was approved by the institutional review board at The University of Colorado Health Sciences Center in Denver, Colo. At the Children's Hospital in Denver, the study was performed after obtaining informed consent from the legal guardian. The study occurred in the operating room at the beginning of elective surgical procedures. Patients from the pediatric otolaryngology, dental, urology, and ophthalmology services were enrolled from July through October 1997. Excluded were patients with a history of sleep apnea; patients scheduled for tonsillectomy or adenoidectomy; patients with asthma or reactive airway disease, craniofacial abnormalities, or variance from neutral position; and patients with abnormal airways (eg, tracheomalacia) as determined by the surgeon or anesthesiologist.

Variables of age, weight, sex, tonsil size, and primary tooth eruption were noted. Tonsil size was rated on a scale of 1+ to 4+. Presence of primary teeth, which may increase the size of the airway by jaw displacement, was scored from 0 to 3: 0, no teeth; 1, incisors only; 2, early erupted molars or molars worn to the gingiva in the case of dental patients who were undergoing restorations; and 3, fully erupted molars.

A force transducer (Omega Corp, Stamford, Conn; 0- to 250-lb load cell) was specifically constructed for this purpose. Preliminary evaluations used a larger-diameter force device that was subsequently modified to a round device approximately the diameter of a US penny. Preliminary evaluations used a drop in the pulse oximetry levels to determine obstruction. This was not reliable and took too long to be applicable to a brief study period of 5 seconds of obstruc-

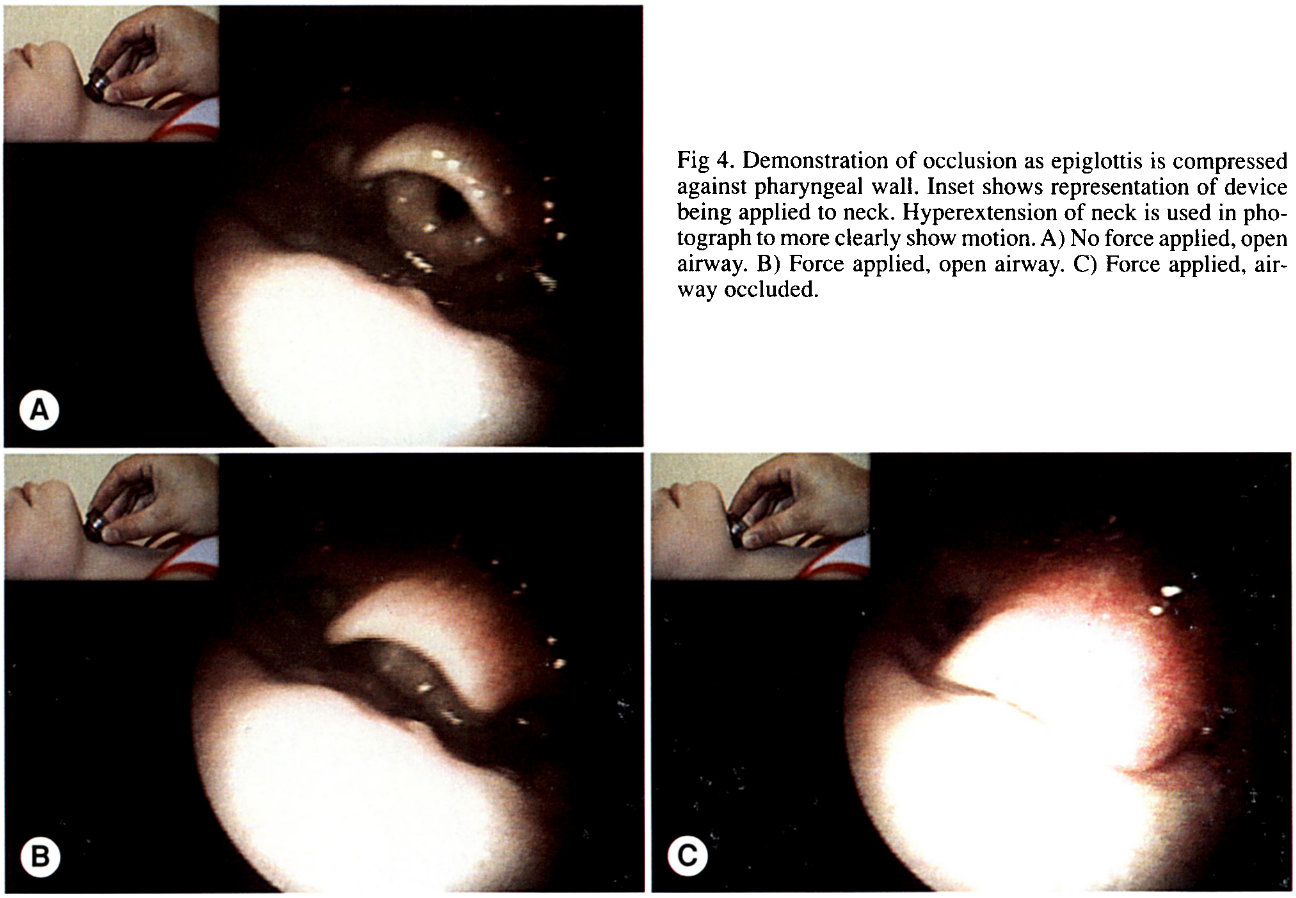

Fig 4. Demonstration of occlusion as epiglottis is compressed against pharyngeal wall. Inset shows representation of device being applied to neck. Hyperextension of neck is used in photograph to more clearly show motion. A) No force applied, open airway. B) Force applied, open airway. C) Force applied, airway occluded.

tion. Using the anesthesiologist's tools of auscultating and observing the cessation of CO_2 output on the monitor was more appropriate for these brief episodes of obstruction. Obstruction was quantified as the absence of sound with respiratory effort. Attempts were made to quantify the obstruction on the basis of auscultation, but were difficult to reproduce among 13 different pediatric anesthesiologists.

A round force gauge 19.5 mm in diameter was applied to an area in the midline centered millimeters above the hyoid bone in a posterior-superior vector (Fig 3). Before each patient's application, the gauge was zeroed and calibrated to a known weight in pounds. The patients received an inhalation induction with halothane, nitrous oxide, and oxygen. Patients were started in the neutral position, and any variance led to exclusion. The neutral position was determined by approximation of the patient's head lying perpendicular to the Frankfort horizontal plane.

This study situation is an artificial situation for suspension. Under general anesthesia, the upper airway muscles relax and are known to be a site of obstruction requiring airway maneuvers. For a child in respiratory distress and losing consciousness, however, the situation may not be that different from general anesthesia. Additionally, 10 children were excluded because they could not tolerate the neutral position and required airway maneuvers. The neutral position can be subtle and lead to variances in data.

Another tool, the Guedel oral airway, was used to help evaluate the obstruction. Selection of the size of the oral airway was the anesthesiologist's choice. The oral airway can paradoxically contribute to obstruction if it is inappropriate in size or placement. Placement of an oral airway that is too small or too far anterior can cause the tongue to be pushed posteriorly. Placement of the oral airway too far posterior can push against the vallecula or the epiglottis, causing narrowing of the laryngeal vestibule.

Once the patient was well oxygenated and at least at the third level of anesthesia as determined by the anesthesiologist, permission to proceed was obtained and the study was performed. Three observers were involved to eliminate bias. The anesthesiologist maintained the airway and used a stethoscope to listen for breath sounds to decide when the airway was 100% obstructed and informed the recorder. Force was applied for 3 separate 5-second investigations. A single observer applied force to the force gauge, blinded to the obstruction and to the numbers on the pressure gauge. The recorder wrote the numbers from the strain

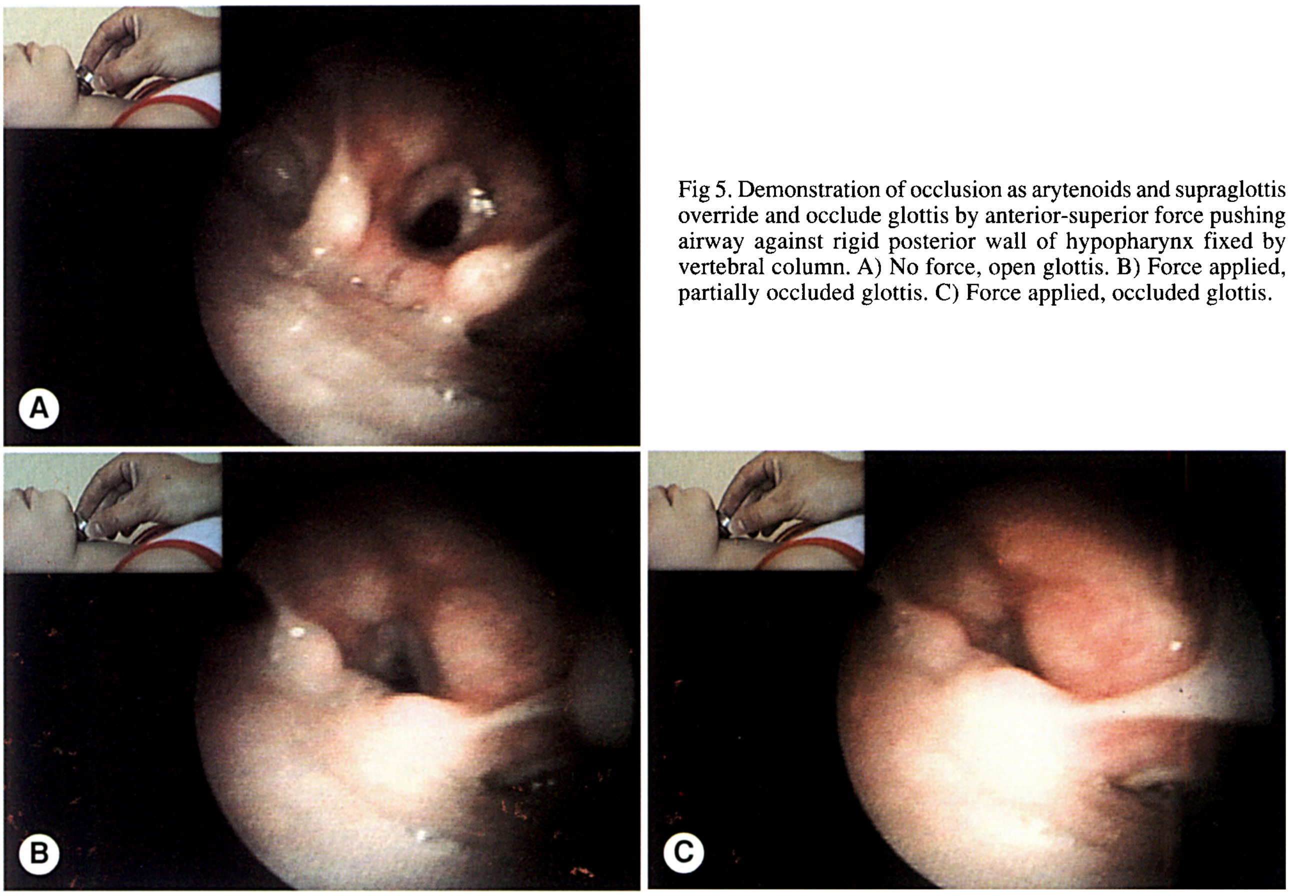

Fig 5. Demonstration of occlusion as arytenoids and supraglottis override and occlude glottis by anterior-superior force pushing airway against rigid posterior wall of hypopharynx fixed by vertebral column. A) No force, open glottis. B) Force applied, partially occluded glottis. C) Force applied, occluded glottis.

gauge when instructed by the anesthesiologist that the airway was obstructed. Confirmation of occlusion was made by observing the absence of CO_2 curves, sampled at the 90° elbow of the pediatric anesthesia circuit of the mask with an Ohmeda 5240 Respiratory Gas Monitor (Ohmeda, Louisville, Colo). Once occlusion was confirmed, the force was removed (Figs 4 and 5). Afterward, the oral airway was selected and placed by the anesthesiologist, and 3 additional applications were performed.

RESULTS

Ninety ASA I and II (American Society of Anesthesiologists physical status classification) children 5 months to 5½ years of age participated in the study. The population included 57 boys (63%) and 34 girls (37%). For statistical purposes, the children were grouped according to age. There was 1 child 0 to 0.5 years, 6 children 0.51 to 1.0 years, 11 children 1.01 to 1.5 years, 17 children 1.51 to 2.0 years, 6 children 2.01 to 2.5 years, 11 children 2.51 to 3.0 years, 10 children 3.01 to 3.5 years, 7 children 3.51 to 4.0 years, 7 children 4.01 to 4.5 years, 12 children 4.51 to 5.0 years, and 2 children 5.01 to 5.5 years. Figure 6 demonstrates the distribution of the children enrolled by age group. Medical histories included 5 children born prematurely, 1 tracheoesophageal fistula repair, 1 set of twins, 1 ventricular-peritoneal shunt, 1 pyloroplasty, and 1 repaired cardiac ventricular septal defect. There were no significant complications and, specifically, no episodes of laryngospasm. During the testing, there was 1 episode of tachypnea and erratic breathing lasting 60 seconds that resolved after repositioning and placement of an oral airway. Another patient had an episode of bradycardia that immediately resolved when the pressure was released. After the study, all surgical procedures were performed as planned.

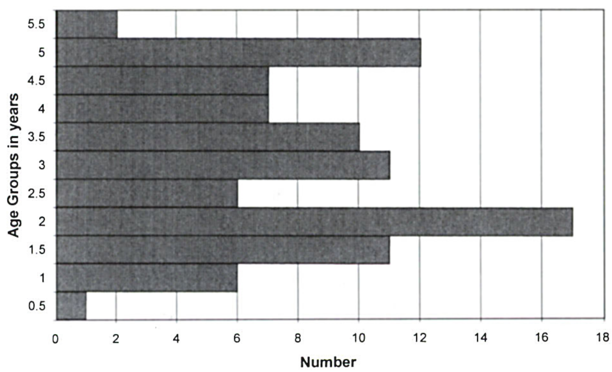

Fig 6. Number of children enrolled per study group based on age.

The 3 forces in each child were averaged before analysis — the range of forces was 0.9 to 21 N (0.2 to 4.6 lb). The mean was 7.1 N (1.6 lb), with a stan-

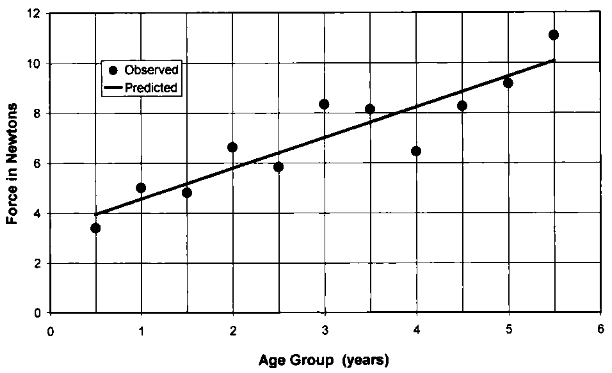

Fig 7. Graph of average force in newtons across age groups. Best fit line, $y = 1.2091x + 3.3455$; $r^2 = 0.8289$.

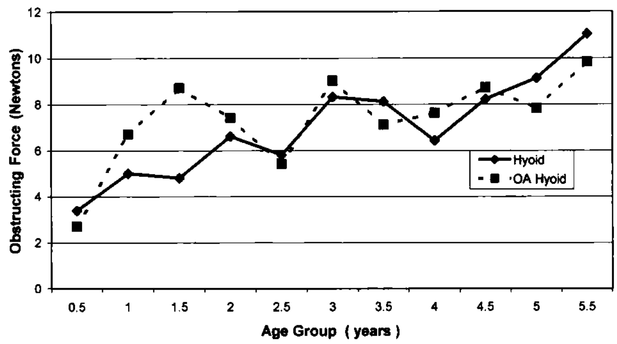

Fig 8. Comparison of obstructing forces and age in data obtained with ("OA hyoid") and without ("hyoid") oral airway. Data are not significantly different with application of oral airway.

dard of error of 0.08 N and a standard deviation of 3.5 N (0.78 lb). A linear graph expressing age versus force is shown in Fig 7. Sex, weight, and tonsil size were not found to correlate with the amount of pressure. After adding the oral airway, the mean became 7.6 N (1.7 lb) with a standard of error of 0.81 N. Figure 8 displays the force required with and without an oral airway. The difference between data obtained with and without the oral airway was not significant for the population studied.

DISCUSSION

The pediatric airway rapidly approaches adult anatomy in the first years of life, yet there are many differences between the airways of infants and adults. Infants have large and heavy heads, the tongue is large, and the larynx is more cephalad. The glottic opening is at the level of the third or fourth cervical spine interspace in full-term infants and descends to the level of the fifth cervical body. Other changes that occur include tooth eruption, with its effect of mandible displacement, especially by the molars that begin to erupt around the first year. The mandible has muscular and fibrous attachments that with anterior and inferior displacement open the airway. This is the mechanism by which intraoral devices help decrease airway collapse in obstructive sleep apnea.

The airway of infants is anatomically vulnerable at the oropharynx between the soft palate and the skull, as described by Tonkin[6] in her hypothesis of sudden infant death syndrome. She found that the mandible is almost horizontal, with a short ramus, and has a soft, cartilaginous mandibular head. The mandible is also more mobile than in adults and can easily be retrognathically displaced in the prone position. This carries the tongue backward and upward against the soft palate, causing occlusion of the airway.

The lack of correlation with tonsil size, tooth eruption, or placement of an oral airway in this study supports the larynx as the site of obstruction. Previously, we reported fiberoptic observations of 8 of our patients and demonstrated that suprahyoid pressure caused the hyoid bone and the thyroid cartilage to move superior and posterior.[7] This caused occlusion at 2 points: the epiglottis was compressed against the pharyngeal wall, and the arytenoids and supraglottis overrode and occluded the glottis by the anterior-superior force pushing the airway against the rigid posterior wall of the hypopharynx fixed by the vertebral column. After a near-hanging, children's airways are more vulnerable than those of adults to delayed edema because of the small diameter. Finally, the young child is unaware of the situation, is unable to realize the danger, and is relatively unable to escape.

The mean force we found needed to occlude the airway of 7.1 N (1.6 lb) demonstrates the ease of airway occlusion in children. The measurement at the fifth percentile (2.2 N [0.5 lb]) is used for injury prevention. This limit is important in designing and evaluating consumer goods for injury prevention.

Events involving the cords of window blinds are one of the situations of unintentional mechanical asphyxia for which this information could be generalized to remove the hazard. Window-blind cords have caused a significant amount of injury in the state of Colorado (unpublished data). Since January 1997, the voluntary standard as proposed by the Consumer Product Safety Commission has been to produce miniblinds with 2 cord tassels or a single break-apart tassel. (Modifications of existing blinds are available; one can telephone 1-800-506-4636 to request tassels and tie-down devices free of charge). Despite these efforts, the products are in use in large quantities, and there is a significant delay for products to be replaced to improve safety.[8] The voluntary change only eliminates a portion of the risk, because long pull cords and slat strings still pose a significant risk to children.

The goal is to have safety built into products. Risk to a child is directly related to the hazard and to exposure (risk = hazard × exposure). The key is developing effective, easy-to-use, passive, "built-in" safety measures that have a minimal or preferably no effect on cost or product use. Active measures that require modifications of human behavior evoke less compliance than passive environmental measures.[9] Research is under way on making this information on childhood airways applicable to products with foreseeable use that could result in hanging or strangulation.

CONCLUSION

The amount of pressure needed to occlude the airway is surprisingly low. Age characteristics should be taken into account to ensure safety under conditions of foreseeable use. Retrospective data have been retrieved from the Colorado State Department of Public Health and Environment and major hospitals over the past 12 years on incidence, clinical course, and outcomes in children 0 to 18 years of age involved in accidental mechanical asphyxia.

Hanging occurs when all or part of the weight of the body causes a ligature to constrict. Our finding no correlation with tonsil size or oral airway application provides information to exclude the tongue, soft palate, and oropharynx as the location of obstruction. Direct observation revealed that obstruction of the airway occurs at the level of the larynx. Accidents may be prevented with improved product design.

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