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INJURY BIOMECHANICS RESEARCH
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Determination of Injury Patterns Under Frontal and Oblique Blunt Impact to the Nasal Tips of Cadavers

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ABSTRACT

Nasal septal injuries are commonly the result of motor vehicle accidents, altercations, and sports and domestic injuries. It has been estimated that up to 50% of all nasal fractures undergoing reduction will develop a secondary deformity or relapse. Therefore, the clinical significance and application of determining septal injury patterns is critical to proper diagnosis and repair. The primary purpose of this study was to determine if blunt impact to the nasal tip of cadavers causes a specific or characteristic pattern of injury to the nasal septum of statistical significance. A secondary purpose was to collect data on parameters of impact and examine them for statistical significance. Test specimens consisted of 16 heads in total, 8 male and 8 female, with ages ranging from approximately 60 to 80 years with four additional specimens serving as controls. In order to impact the nasal septum in a controlled manner, a portable drop tower was designed and fabricated for this particular experiment. The drop tower consists mainly of two components: the cranial mounting box and an instrumented weighted impactor. The specimens were rigidly fixed in the mounting box with the nasal complex facing upward and both the sagittal and Frankfort planes perpendicular to the base plate for a frontal impact. Eight of the sixteen tests were an oblique impact where the head was rotated laterally 15 degrees. Once the test setup was complete, the impactor was released and descended along guide rails until impacting the nasal complex. Impact forces were recorded by a load cell aligned with the impactor. A clinical nasal examination was conducted before and after each impact as well as a post-impact nasal dissection and analysis. The analyses revealed that all injuries occurred in the articulations of the quadrangular cartilage with the surrounding bone inferiorly, posteriorly and superiorly. The injuries can best be described as dislocation at the area of articulation with surrounding bony septum and the majority can be classified as Type 2-C severity. Our clinical observation that all sixteen tests resulted in only one basic pattern of injury (with varying degrees of severity) has a probability of purely random happenstance of 0.0015%. We concluded that the repeated observation of this injury pattern was highly significant (p=0.000015), with a confidence interval of at least 99.98%. In addition, there was no statistically significant correlation identified between the observed injury pattern and gender, angle of impact, or impact force. Our findings suggest that a clinical classification system should be proposed specifically addressing injury to the nasal septum upon impact of the tip. It is hoped that utilizing such a concept will help improve the description, diagnosis, treatment and outcomes of septal injuries resulting from impact to the nasal tip.

INTRODUCTION

Nasal septal injuries are commonly the result of motor vehicle accidents, altercations, and sports and domestic incidents. Over the past several decades, the nature and severity of injuries seen from motor vehicle accidents have changed. In the past, lower speed nonfatal crashes in vehicles not equipped with seat belts, shoulder straps and air bags increased the incidence of more severe injuries of the facial skeleton. Today, widespread use of more effective restraints and air bags combined with higher crash speeds tend to produce extremes of injury, being either fatal or light. Therefore, while severe facial fractures may be less likely to occur, isolated septal injuries are possibly more common (Holt, 1999).

It has been estimated that up to 50% of all nasal fractures undergoing reduction will develop a secondary deformity or relapse and has been demonstrated by many authors that an initial, accurate open reduction of the septum decreases this relapse rate dramatically (Clark et al., 1983, Harrison, 1979, Holt, 1978, Murray et al., 1986, Murray et al, 1984, Rohrich et al., 2000). As a result, the clinical significance and application of determining septal injury patterns is manifold. A classification system could prove extremely critical for proper diagnosis and repair. It is reasonable to assume that anticipation of specific patterns of septal injury would increase the accuracy and timeliness of clinical diagnosis. It follows that a more appropriate surgical approach and therapy would result, yielding a concomitant decreased incidence of secondary nasal deformity. Prevention of such injuries may also be enhanced with a more complete knowledge of injury patterns.

The primary purpose of this study is to determine if blunt impact to the nasal tip causes a specific or characteristic pattern of injury to the nasal septum of statistical significance. In addition, data on parameters of impact will be gathered and examined for statistical significance. To date, to our knowledge, the existence of a specific nasal septal injury pattern has not been proven (although others have used the terminology and concept) in the context of a controlled setting, applying generally accepted methods of statistical analysis for significance. Also, no study has exclusively examined initial impact confined to the nasal tip, a common site due to its prominence. In general there is a relative paucity of data specifically addressing the nasal septum, and even less, that has any kind of scientific or statistical method applied. Evidence provided is often anecdotal, usually retrospective, and accounts for most published reports.

BASIC ANATOMY

A brief review of the pertinent anatomy of the nasal septum and adjacent structures is in order to better appreciate the pathomechanics, study results and understand their implications. The nose is composed of the external nose and the nasal cavity. The nasal cavity is divided into right and left halves by the nasal septum (Larrabee et al., 1993, McMinn, et al., 1994). The septum has a larger posterior immobile portion, and a much smaller anterior mobile portion (Figure 1).

The larger immobile portion is composed of both bone and cartilage. Posterior composition consists of the perpendicular plate of the ethmoid above which articulates with the vomer and a small portion of the palatine bone below. Anterior composition is mainly the quadrangular (septal) cartilage, which articulates with the mobile septum caudally, nasal bones and upper lateral cartilages dorsally, perpendicular plate of the ethmoid and vomer posteriorly, and maxillary crest and anterior nasal spine of the maxillary bones inferiorly. The upper lateral cartilages are actually continuous with the quadrangular (septal) cartilage. Bone is covered by periosteum and the cartilage is covered by perichondrium; which for the most part are not continuous. These layers are in turn completely covered with respiratory mucosa which is continuous.

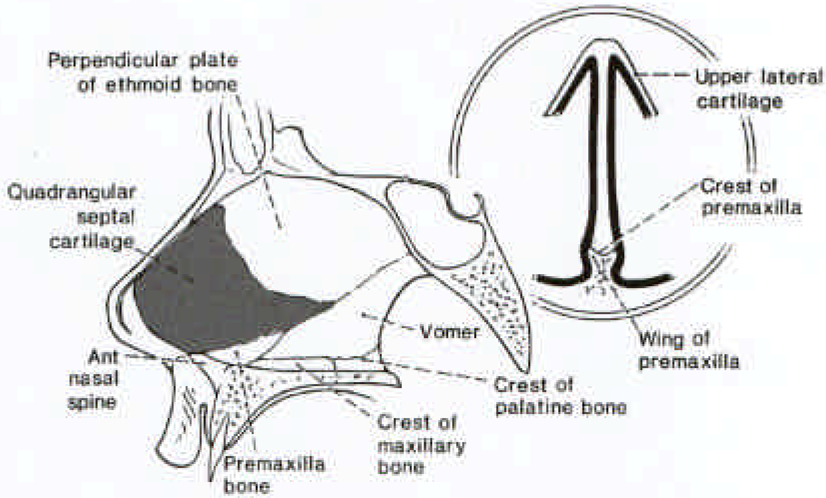

Figure 1. Composition of the nasal septum.

The smaller mobile portion is composed of the membranous septum and columella. The membranous septum is connective tissue covered by skin. The columella is composed of the cartilaginous medial crura, muscle, and connective tissue all covered by skin. Often the terms membranous septum and mobile septum are used as synonyms.

This study focuses on the junction of the quadrangular cartilage and the bony components of the septum (Figure 2). This is highly flexible and dissipates energy transmitted to the caudal nose, thereby protecting the caudal end of the quadrangular cartilage. Of particular clinical importance to this study, are the nature of the articulations between quadrangular (septal) cartilage and bony components of the septum. These articulations are anatomically peculiar because cartilage does not usually articulate directly with bone. This conformation allows for movement. Connective tissue between the cartilage and bone tends to be looser, and may occasionally contain fat. There are grooves in the ethmoid, vomer, and maxillary bone to receive the cartilage. In the area of the maxillary crest there is often flaring of the lips of the grooves (premaxillary wings) to the extent that the articulation is almost flat. The septal cartilage tends to expand laterally here also. The strength of the articulations depends on the opposed surfaces rather than on continuity of the perichondrium and periosteum. Therefore, improper development, fracture of a lip of the groove, or trauma to the area may result in dislocation of the quadrangular (septal) cartilage (Hollinshead, 1982) as depicted in Figure 2.

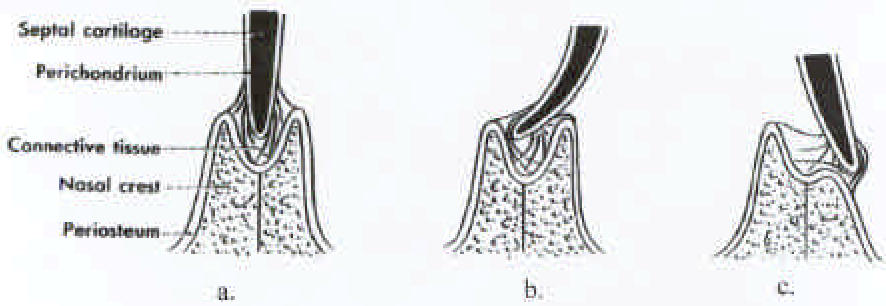

Figure 2. Junction of the septal cartilage with surrounding bone as shown in (a); (b) demonstrates the method of cartilage articulation so as to allow flexion; (c) indicates how dislocation is favored by defective development of nasal crest.

METHODOLOGY

Subjects

Twenty human cadaver heads were provided by the University of Maryland Anatomical Services Division in order to conduct this study. The heads were unembalmed and stored in an arid freezer shortly after death. Test specimens consisted of 16 heads in total, 8 male and 8 female, with an additional four heads used as controls. All of the test heads were Caucasian with the exception of one African American male subject. A single arbitrary drop height and weight to use for the tests was chosen through trial and error with the test heads. These impact parameters were chosen because they would cause fracture in 100% of nasal septal specimens, while at the same time causing little to no collateral damage to the surrounding facial bones.

Experimental Design

A 2x2 full factorial, replicated x3 (16 total tests) was used. The experiment was randomized and prospective in nature. It was determined that the variables gender and angle of impact could be varied and still have adequate power and validity. Equal numbers of male and female heads were used and the angle of impact included two discrete angles, the first 0 degrees to the sagittal plane and the second 15 degrees. This would determine if gender or angle of impact would predispose the nasal septum to a particular injury pattern.

Equipment

The experiments were conducted at the anatomy laboratory located within the University of Maryland Anatomical Services Division. A portable drop tower was designed and fabricated by engineers in the Biomechanics and Injury Prevention Office at the Johns Hopkins University Applied Physics Lab (JHUAPL). The device was designed to deliver impacts to the facial skeleton, and in particular the nasal complex, of cadaveric subjects in a controlled, repeatable manner. It consists primarily of two components; namely the cranial mounting box and an instrumented impactor (Figure 3).

The design of the cranial mounting box was governed by typical anthropometry and used three adjustable, heavy gauge, pointed screws to rigidly hold the head in space. The instrumented impactor consisted of a 3.2 mm thick aluminum plate bolted to two cylindrical collars that slid along vertical guide rails. Mounted to the center of the plate was a 51 mm long impactor rod with a 25 mm diameter aligned with a load cell (Entran 2000 ELW) for recording the impact forces. A TDAS Pro data acquisition system (Diversified Technical Systems, Inc.) was used to capture the data during impact. The TDAS software was used to filter the data at SAE Class 1000.

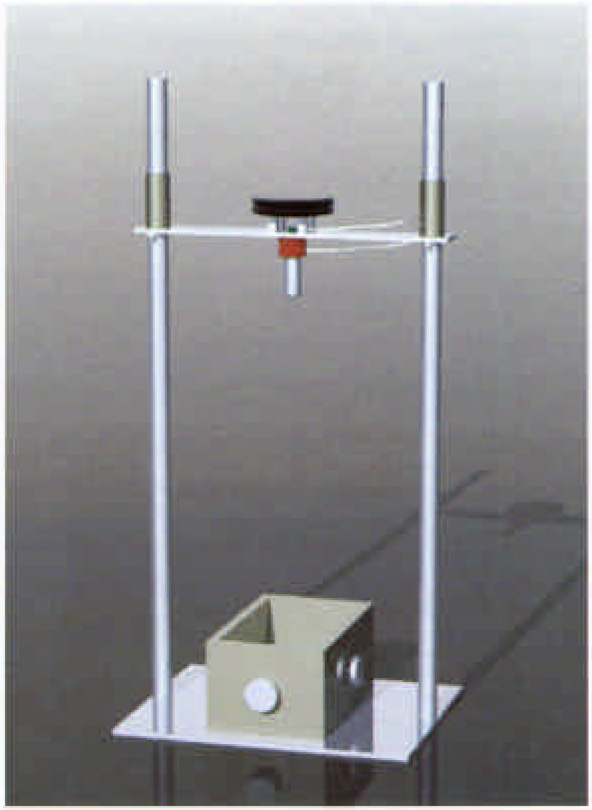

Figure 3. Portable drop tower.

Test Methods

Prior to impact, each specimen was subjected to a clinical nasal examination in search of evidence showing prior nasal trauma or surgery. If the subject had no signs of trauma or surgery, the cadaver head was placed into the mounting box and, with the nasal complex facing upward, a screw was inserted into each external auditory canal orienting the sagittal plane of the head perpendicular to the base plate of the drop tower. The head was rotated into impact position by ensuring the Frankfort Horizontal plane was also perpendicular to the base plate. This position was maintained by a third fixation screw inserted into the outer table of the calvarium. This allows rigid three point bony fixation of the head under moderate to severe impact forces (Figure 4).

Once a specimen was positioned in the box, the impactor rod was lowered and aligned with the nasal tip. The impactor, with a total weight of 5 kg, was then raised to a height of 35 cm from the nasal tip and locked into position. Once the data acquisition system was set for triggering on impact, locking pins were then released and the impactor descended along the guide rails until impacting the nasal complex. A post-test nasal examination was conducted on each subject in order to determine injuries that resulted from the impact. Furthermore, once all of the impacts were complete, each specimen underwent a meticulous dissection and pathological examination for closer study. The septum was subjected to gross and microscopic inspection for the presence and location of fractures and mucosa tears. All injuries from both the clinical and pathological exams were documented.

Figure 4. Test setup with cadaver head rigidly fixed in space and nasal complex rotated 15 degrees with respect to sagittal plane.

RESULTS

Injury Classification System

Specific to this study, injury is defined as any disruption of an otherwise continuously intact septum, which could include fracture, dislocation, tear, avulsion or any combination thereof. The observed injuries were categorized by a classification system based on their location and severity. The injury locations were divided into four Injury Zones (A,B,C,D) which followed along the junction between the quadrangular cartilage and the surrounding bony components of the septum (Table 1). Each injury's severity was evaluated by determining in which zones the injury occurred (Figure 5). Based on the extent of the damage, the injuries were classified into an Injury Type (1,2,3,4) (Table 2). Finally, the injury could also be classified as either open (O) or closed (C). An "open" injury is defined as penetration of the mucoperichondreum/periosteum and protrusion of the septal fragments into the nasal cavity, whereas a "closed" injury does not have the penetration of this layer nor the protruding fragments.

Table 1. CLINICAL INJURY ZONES

Clinical Injury Zone	Location
A	Junction area between the QC and ANS/MC; palpable injury
B	Junction area between the QC and V;palpable injury
C	Junction area between the QC and PPE; palpable injury
D	Junction area between the QC and NB at R; palpable injury

QC= quadrangular cartilage; ANS = anterior nasal spine; MC = maxillary Crest; V = vomer; PPE = perpendicular plate of ethmoid; NB = nasal bones; R = rhinion

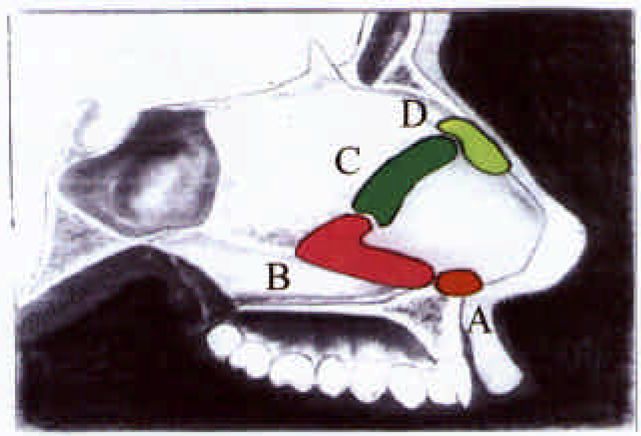

Figure 5. Clinical Injury Zones

Table 2. CLINICAL INJURY TYPES

Clinical Injury Type	Extent of Injury
1	Zone A
2	Zone A + B
3	Zone A + B + C
4	Zone A + B + C + D

Clinical Observations

The injuries observed in this study are best described as dislocations, which occurred in the articulations of the quadrangular cartilage with the surrounding bony septum. None of the specimens exhibited fracture through the body of the quadrangular cartilage or the surrounding septal bones with the only exception being the anterior nasal spine. The articulation in this area remained intact 100% of the time with disruption occurring 2-3 mm inferior via fracture of the bone.

The predominant injury pattern was Type 2-C of which 63% of the cases fit into this classification. This injury can be described as crescent shaped or half- "C" shaped injury (Figure 6a). Approximately 31% of the injuries were Type 3-C, described as a "C" shaped injury (Figure 6b) The remaining 6% (one case) had an injury of Type 4-C. All sixteen of the injuries were closed. It is also important to note that no isolated Zone D, Zone D + C, or Zone D+ C+ B injuries occurred. Rather, there appeared to be a progression of injury starting from Zone A and advancing posteriorly and superiorly through Zones B, C, and D.

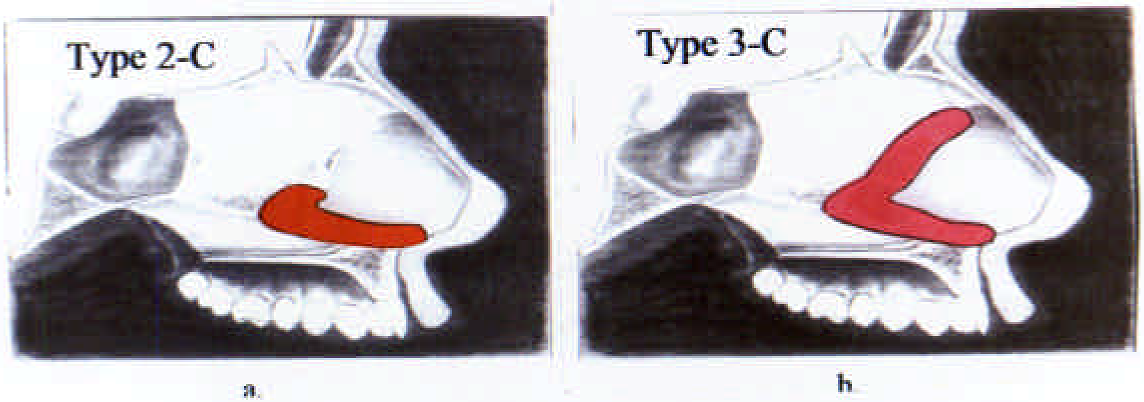

Figure 6. a. Predominant type of injury pattern: Type 2-C (half-"C" shape);
b. Second most common type of injury pattern: Type 3-C ("C" shape).

Statistical Analysis

The null hypothesis for the primary or main part of this experiment stated there was no discernable injury pattern. In other words, it was expected that several random injuries throughout the septum would be observed, including the body of the quadrangular cartilage, articulations with surrounding bone, and the bone itself. Using a binomial distribution analysis, the assumption was made that there is an equal theoretical probability that injury will occur along an area paralleling the articulations versus any other location. However, post-test results show the null hypothesis to be false and conclude the observation of the basic pattern of injury was highly significant ($p=0.000015$), with a confidence interval of at least 99.98%.

The secondary part of the experiment included evaluating the correlation between the impact parameters (impact force, specimen gender, and impact angle) and the resulting clinical injury patterns. The null hypotheses for this part were that there would be no difference either between gender (Male vs. Female), angle of impact (0 degrees to sagittal plane vs. 15 degrees to sagittal plane), or impact force in regard to injury patterns. Post –test results show this null hypothesis to be true for all three parameters. Using F Ratio Hypothesis Test Analysis of Variance for Gender, this probability is 0.70. Mean values were 2.50 ± 0.53 and 2.38 ± 0.74 for females and males, respectively. Using the same analysis for impact angle, the probability is 0.25, which is not a significant difference from 0.50 (perfect random occurrence). A paired t-Test compared impact force and injury patterns, but showed no cause and effect relationship.

Sensor Data

Impact forces were recorded from the load cell aligned with the impactor. The mean of the peak loads recorded during impact was 2499 ± 173 N. The mean values were 2613 ± 276 and 2363 ± 344 N for straight on and oblique impacts, respectively. A comparison of representative force curves from the two impact orientations is presented in Figure 7. The response pattern was very similar for both curves including an initial non-linear region, followed by a linear region rising to a peak, and ending with a return to no-load conditions. However, one noticeable difference was an initial force rise and fall peak prior to the peak force in the impact with the nose aligned at 0 degrees with the sagittal plane. It is theorized that this is due to the bending mode of failure in which the dislocation of the cartilage-bone junction occurs. The cartilage experiences compression and a rise in applied force until it bends to one side or another. This causes the slight drop in force which then continues to rise once the cartilage has been re-oriented and can support the load. The absence of this initial peak in the oblique impacts may be due to the fact the cartilage is already oriented so that it will immediately experience bending when a load is applied.

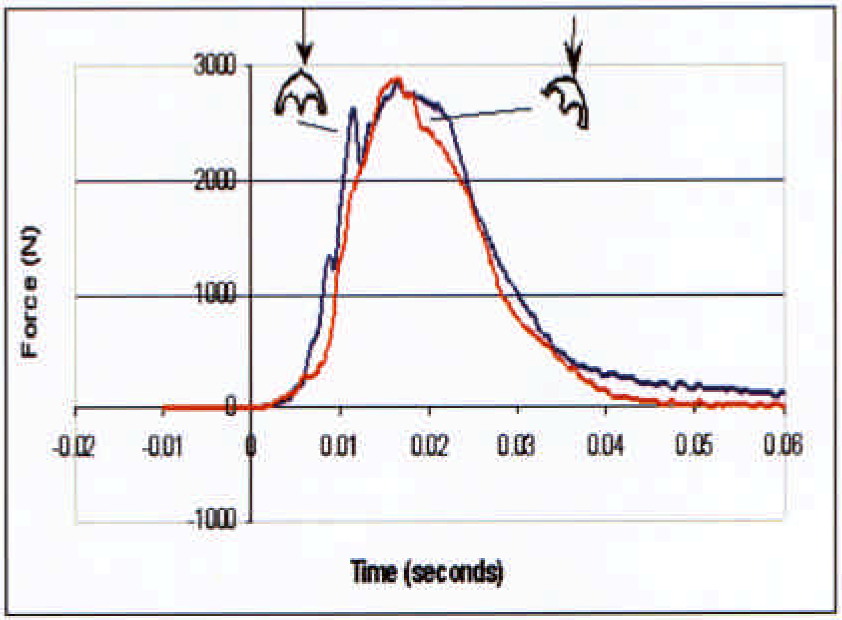

Figure 7. Comparison of impact response for the nasal tip rotated 0 and 15 degrees with respect to the sagittal plane.

DISCUSSION AND CONCLUSIONS

The findings of this work identify a discrete pattern of nasal septal injury resulting from blunt impact to the nasal tip. Location of injury is mainly within the articulations between the quadrangular cartilage and surrounding bony septum. This resulting injury pattern was shown to be highly statistically significant. The nature of these injuries can best be described as a dislocation of the septal cartilage, not a fracture through the cartilage or bone itself. Two predominant variations or types of this pattern emerged, the half-"C" shaped and "C" shaped injuries. Based on these findings, a clinical classification system was proposed specifically addressing injury to the nasal septum upon impact to the tip. It is hoped that utilizing such a concept will help improve the description, diagnosis, treatment and outcomes of septal injuries resulting from impact to the nasal tip.

The pattern identified in this work, while in conflict with other author's observations of exact injury location within the septum (i.e. in this study being mostly through the articulations, and not the body of cartilage or bone); is however, in general agreement with regard to the characteristic "C" shaped injury noted by Harrison and others (Clark et al., 1983, Harrison, 1979, Murray et al., 1986, Murray et al,). These findings theoretically support Harrison and Murray et al. and their contention that failure to reduce septal fragments that overlap or interlock edges, causes recurring deformity in the septum and nasal bones (Harrison, 1979, Murray et al, 1984, Fry, 1967). The results observed here are also consistent with, and can be explained by, detailed anatomic descriptions of the septal cartilage-bone articulation previously published in noted anatomical texts (Hollinshead, 1982).

Similar peak force levels and injury patterns were recorded for all tests. This implied that failure of the bone-cartilage junction was independent of specimen gender or orientation during impact and that neither of these variables influenced the impact response and resulting injury pattern. However, one possible speculative explanation for the existence of a predetermined and recurring injury/dislocation pattern is teleological. The pathomechanics of the injury suggest that the impact energy "finds" the most susceptible structure and proceeds, in step, to the next most vulnerable. In this case, the most susceptible structure was the bone-cartilage junction beginning in the anterior section of the septum and proceeding posteriorly and superiorly. Therefore, the transmission of traumatic forces to the cribriform area is prevented from occurring, with the majority of the force being dissipated at the injury/dislocation. This in turn prevents damage to the anterior cranial fossa and the potential for a much more serious injury. Perhaps the widespread prevalence of deviated septum in the general population is not a deformity, but an intended conformation designed to ensure a more predictable injury/dislocation of the septum under traumatic conditions.

Surgical significance of our findings emphasizes the importance of accurate reduction of septal fragments caused by injury of any type, which may require aggressive open reduction. Rohrich et al present compelling evidence for aggressive open reduction of septal fragments in cases of significant septal involvement, thereby reducing their nasal revision rate to 9 percent (Rohrich, et al., 2000). Practical non-surgical applications of this information include septal injury prevention. Perhaps improvement in the design or deployment of motor vehicle air bags could be facilitated Design of more effective nasal protective gear for use in sports and work may also be an off-shoot (Holt, 1999).

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DISCUSSION

PAPER: **Determination of Injury Patterns Under Frontal and Oblique Blunt Impact to the Nasal Tip of Cadavers**

PRESENTER: ***Andrew Merkle, APL Lab, John Hopkins University***

QUESTION: *Guy Nusholtz, Daimler Chrysler*

Your data seems to be sensored. How do you know when you had an injury and when you didn't have an injury and how do you relate your forces or how do you do any sort of statistics with forces related to the injury to sort through some type of risk with respect to either gender or with respect to the actual impact?

ANSWER: So the question is how do we relate the forces to the --

Q: You've got sensored data. In other words, it could have broken at 500 Newtons and not 3,000?

A: Correct.

Q: The way you're doing the impact by not being near the threshold may contaminate your data because it's sensored for you to come up with any statistical correlation. How do you sort through that?

A: Well, we've addressed the subject and more tests would need to be done at varying force levels initially. But this was just our current assessment from the limited number of tests that were already done. And we just assumed basically off the data we had that this is where the peak forces of where we were getting the majority of fractures. That the energy would continue to propagate in the nasal path until all of it was dissipated. So, that's why we had the different zones of varying magnitude. But to be conclusive we would have to conduct more tests.

Q: *Frank Pintar, Medical College of Wisconsin*

Very nice presentation. I might have missed it, but did you say anything about the area of impact or the impact surface area?

A: One inch circular diameter.

Q: Do you think that has anything to do with it or did you just pick it because it was available?

A: We had seen it as a common use in other experiments so we wanted to kind of stay within the realm of what had been done. We had a two inch one and half inch one made up for testing. But with the limited test subjects that we had privy to we didn't want to start carrying too many, changing too many variables. So, again in the same realm there would need to be more tests done to see if that had an influence.

Q: I was wondering because it's a fairly soft area whether it actually bottomed out and you had an edge effect or anything on impact?

A: No. We did have some video from it and we made sure that there was no bottoming out. I think there was one case we did have it and we actually removed that from the study. That was a relatively older subject that was pretty frail and it looked like there was not much structure left.

Q: You didn't limit the displacement then?

A: No, we didn't, no. It's hard to understand from seeing this you'd have to actually watch it. But it seems like it's a lot of force that was imparted to it, but it didn't take much force to fracture or cause the dislocations.

Q: *Erik Takhounts, NHTSA*
I may extend Frank's question a little bit. How relevant is your data to the automotive environment where we have most loads with the airbags and you have concentrated load with your impactor, which also is size dependent apparently?

A: Well, in this case it may not be extremely relevant. There would have to be more tests. What we were showing was the assessment due to these results --

Q: Do you plan to extend your research to airbag?

A: We're looking into it. This was actually done, as a small collaboration with Hopkins and it was an internal project. So if you have funding.