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Fracture Pattern Interpretation in the Skull: Differentiating Blunt Force from Ballistics Trauma Using Concentric Fractures*

ABSTRACT: There have been several anthropological studies on trauma analysis in recent literature, but few studies have focused on the differences between the three mechanisms of trauma (sharp force trauma, blunt force trauma and ballistics trauma). The hypothesis of this study is that blunt force and ballistics fracture patterns in the skull can be differentiated using concentric fractures. Two-hundred and eleven injuries from skulls exhibiting concentric fractures were examined to determine if the mechanism of trauma could be determined by beveling direction. Fractures occurring in buttressed and non-buttressed regions were examined separately. Contingency tables and Pearson's Chi-Square were used to evaluate the relationship between the two variables (the mechanism of trauma and the direction of beveling), while Pearson's r correlation was used to determine the strength of the relationship. Contingency tables and Chi-square tests among the entire sample, the buttressed areas, and the non-buttressed areas led to the null hypothesis (no relationship) to be rejected. Pearson's r correlation indicated that the relationship between the variables studied is greater than chance allocation.

KEYWORDS: forensic science, forensic anthropology, trauma analysis, blunt force trauma, gunshot wounds, concentric fractures, beveling

Anthropological research of traumatic processes resulting from weapon wounds encompasses a wide variety of topics such as the timing of injury (1), the sequence of traumatic episodes (2), cannibalism (3), mass disasters (4), burned remains (5,6), sharp force trauma (7,8), blunt force trauma (9), and ballistics trauma (10). While all of these areas of study provide valuable insight into traumatic processes, three mechanisms of trauma including sharp force, blunt force and ballistics trauma provide important information about weapons used. The ability to differentiate between sharp force, blunt force, and ballistics trauma allows for an indication of the events surrounding death.

In the case of sharp force trauma, the presence of cut marks can link the injury to the weapon used. Conversely, the indicators of blunt force and ballistics trauma tend to be less discriminatory, leading to difficulties with diagnosis of the mechanism of injury when the impact site is missing.

The most obvious morphological difference between blunt force and ballistics trauma is the site of impact. The appearance of the impact site in blunt force trauma varies according to the striking object as well as the amount of energy used to produce the wound (Fig. 1), whereas ballistics trauma displays a more distinctive pattern than blunt force trauma (Fig. 2). In the rare instances where the impact site is absent or missing in blunt force or ballistics trauma, other techniques of fracture patterns must be employed (11).

If the kinetic energy is high enough, then secondary and tertiary fractures may form in addition to the primary impact. Secondary fractures include linear or radiating fractures while tertiary fractures are curvilinear concentric fractures. Concentric fractures form and terminate perpendicular to radiating fractures, giving the wound a spider-web appearance (Fig. 3). The numbers of generations or consecutive concentric fractures may reflect the velocity of the projectile (Fig. 4) (12). In some cases, concentric fractures may form when radiating fractures are not present (13).

Concentric fractures in the skull are produced dissimilarly in blunt force and ballistics trauma. Since bone breaks on the tension side first, concentric fractures will fracture first on the outer table in blunt force trauma and on the inner table in ballistics trauma. This should create internally beveled concentric fractures in blunt force trauma and externally beveled fractures in ballistics trauma (Fig. 5). In this study, beveling refers to the angle between the outer and inner tables on the fracture surface (14).

Secondary and tertiary fractures in blunt force and ballistics trauma to the skull often appear similar on initial examination. Fracture pattern interpretation can be useful in determining the mechanism of trauma when the impact site is missing. Since concentric fractures have a characteristic curved appearance, locating them in fragmentary remains may be easier than finding the impact site. Furthermore, blunt force and ballistics trauma have been examined in great detail within anthropological literature (9,10,15–20), but few studies (11,14,21) have attempted to distinguish between these two categories of trauma.

This study examines the beveling direction of concentric fractures to the skull in blunt force and ballistics trauma to differentiate these mechanisms of trauma. The hypothesis of this study is that blunt force and ballistics trauma can be differentiated by the pattern of beveling in concentric fractures. The null hypothesis in the tests that follow is that the mechanism of trauma is not associated with the direction of concentric fracture beveling.

Bone Biomechanics and Fracture Production

Bone biomechanics studies are germane to any discussion of trauma analysis, because bone behaves in a predictable manner to stress. Newton's third law of motion, which states that for every

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FIG. 1—*Blunt force trauma to the skull. Deformation is found around the impact site and the surrounding areas. Concentric fractures are also present in the left–hand side of the photo. Photo by author.*

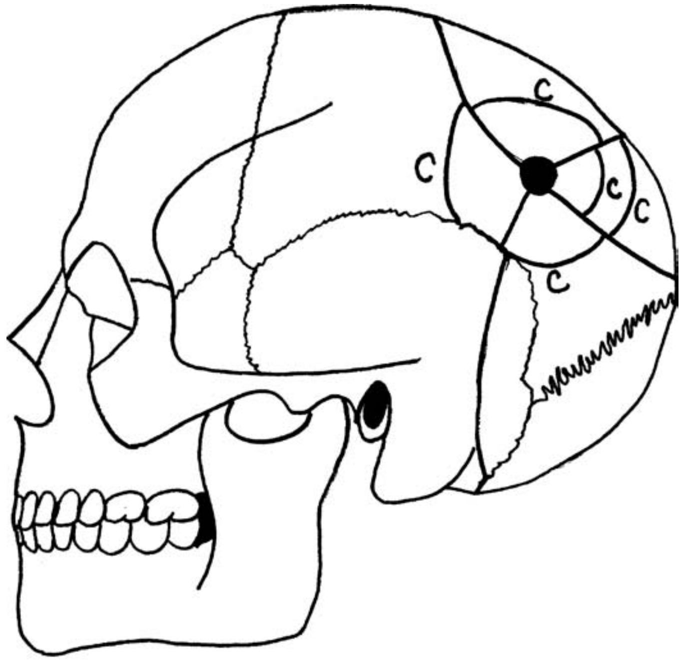

FIG. 2—*Example of an entrance (bottom defect) and an exit (upper defect) in ballistics trauma. The location of the concentric fractures indicates that these fractures occurred before the projectile was able to exit the skull. Photo by author.*

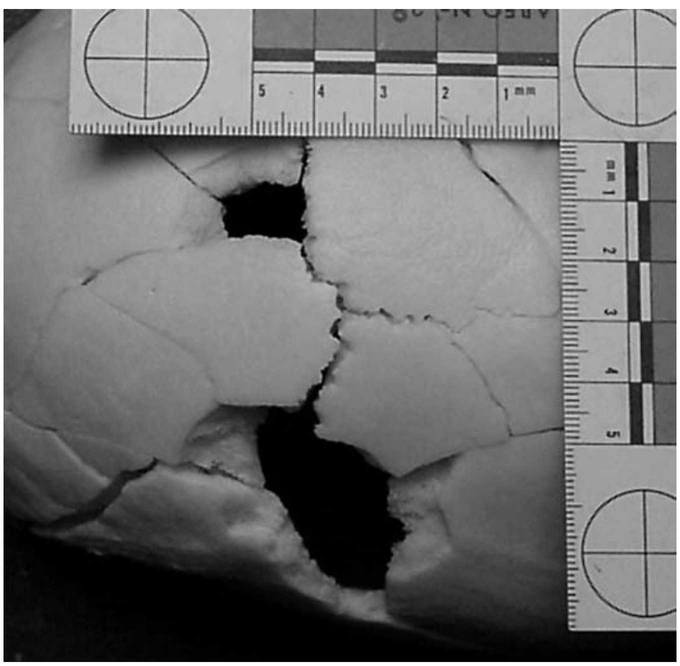

FIG. 3—*Illustration of a typical fracture pattern commonly associated with blunt force and ballistics trauma. Illustration by author.*

FIG. 4—*Photograph of blunt force trauma to the skull displaying the presence of multiple generations of concentric fractures. Photo by author.*

action there is an equal and opposite reaction, is applicable in understanding fracture production and propagation. Force or load changes set bodies into motion. There are three types of forces acting on bones, which include external forces acting on the body, internal forces caused by muscle contraction or ligament tension, and internal reaction forces between bones (22). Force may be described by magnitude, position of the action line of force within the body, and the direction of force along the line of action.

Stress and strain are "phenomena occurring within a body to which a force has been applied" (23:4). Stress or deformation is force that is applied to an object, and strain is a change or distortion (24). Factors that influence a bone's reaction to stress and strain include the elasticity, ductility, and stiffness of a bone. Elasticity allows bone to return to its original size and shape after a load has been removed. Stiffness allows a bone to resist deformation when a force is applied. Finally, a ductile material is any material that can undergo a large amount of deformation before breaking. The mineral component of bone is rigid, while the collagenous

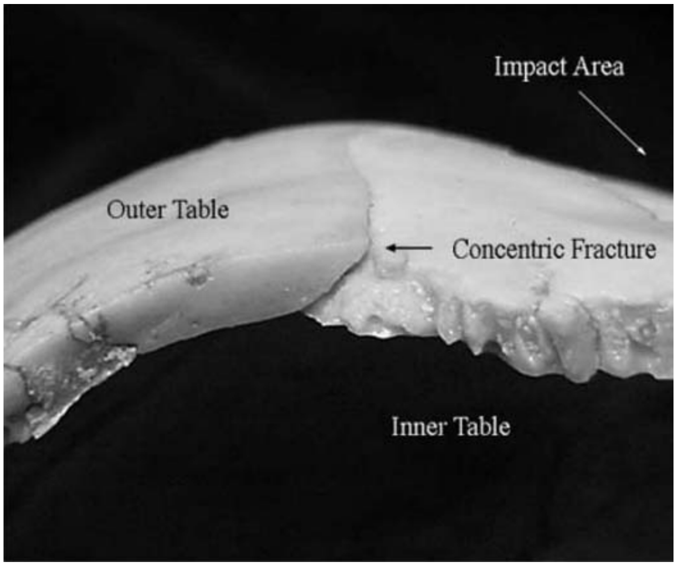

FIG. 5—*This photograph displays the beveling direction (internal) in a concentric fractures associated with blunt force trauma. Photo by author.*

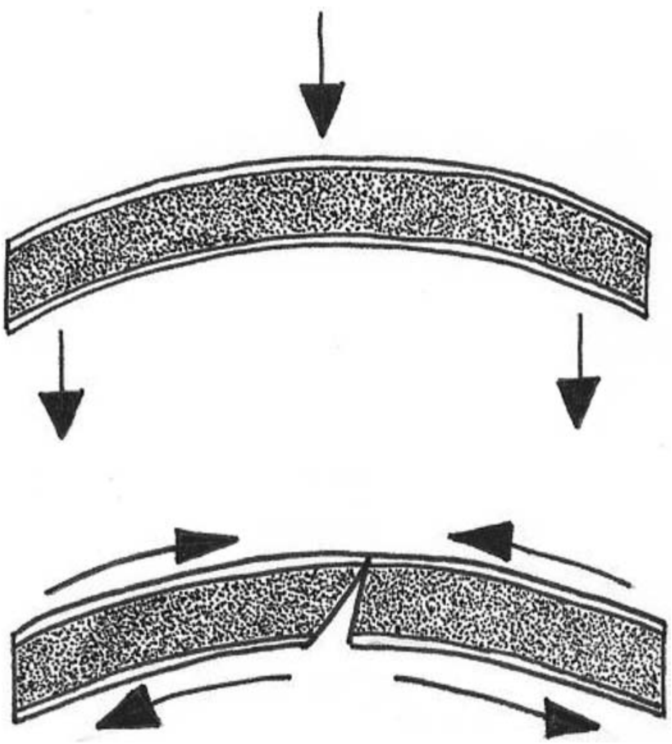

FIG. 6—*Diagram of the typical fracture pattern of bone to fracture first on the side of tension. Illustration by author.*

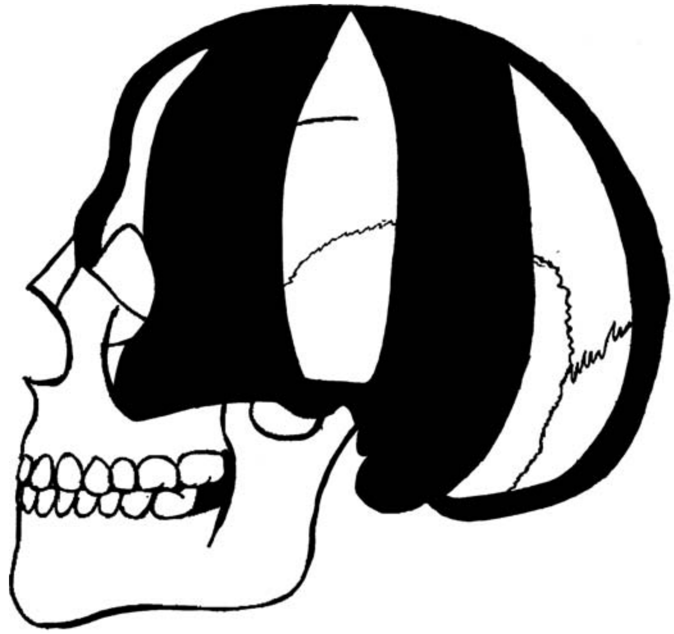

FIG. 7—*Illustration of the six areas of natural buttressing of the skull, which appear as six horizontal strips throughout the skull (27). Illustration by author.*

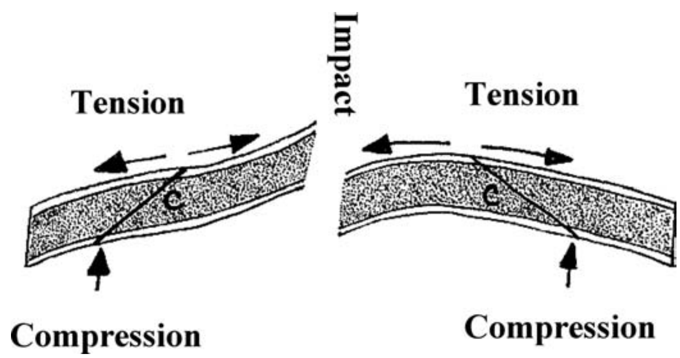

FIG. 8—*This diagram illustrates the sequence of events in concentric fractures associated with blunt force trauma. Illustration by author.*

component of bone is ductile. The combination of these three ingredients allows for bone to be strong and flexible at the same time; thus causing bone to be similar to mild steel in its response to a load, but stronger than steel in resistance to bending (23).

There are several principles of bone biomechanics that dictate how and when a bone will fracture. The most important principle in terms of this research is Poisson's ratio (Poisson's ratio (v) = lateral stain/longitudinal strain), which states that as deformation occurs in one direction there will be complementary changes in other directions (24). At the point of impact, compressive forces are pushing the bone, while tensile forces are tearing the bone apart on the opposite side (Fig. 6). Bone then fails in tension and the fracture travels to the compression side (25). Poisson's ratio is important, because it allows for a prediction of where the bone will fail first (26). The principle allows for an accurate prediction of the beveling direction in concentric fractures.

The buttressed areas of the skull are thought to play a part in the prediction of fracture patterns. Buttressing occurs as natural thickening in six areas of the skull in the midfrontal, midoccipital, parietosphenoidal, and parietopetrous areas (Fig. 7). It is theorized that these regions allow the bone to be stronger and more resilient under loading. Some believe that fractures will avoid the buttressed areas, because fracture patterns follow the path of least resistance (9). This could affect the appearance of fracture patterning and affect the directional beveling of concentric fractures (27).

There are multiple differences in the appearance of fracture patterns in blunt force and ballistics trauma. Blunt force trauma involves a slow moving object striking a relatively large area with velocity measured in miles per hour, whereas ballistics trauma involve a quickly moving object striking a small area with velocity measured in feet per second (21).

At the site of impact in blunt force trauma, compression increases on the outer table and tension increases on the inner table. In the areas surrounding the impact site (Fig. 8), tension increases on

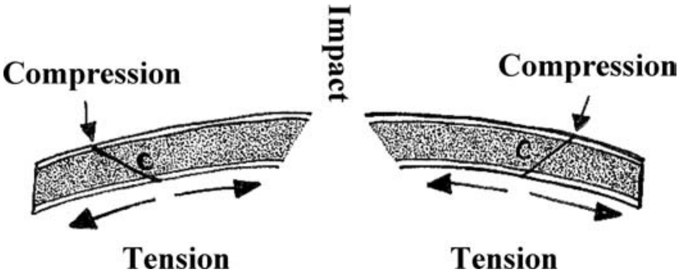

FIG. 9—*This diagram illustrates the sequence of events in concentric fractures associated with ballistics trauma. Illustration by author.*

TABLE 1—*Distribution of the cases analyzed for the study.*

	Blunt Force Trauma	Ballistics Trauma	Total (%)
Regional Forensic Center	64	72	136 (83.4)
National Museum of Health and Medicine	15	10	25 (15.3)
National Museum of Natural History	0	2	2 (1.2)
Total (%)	79 (48.5)	84 (52.5)	163 (100)

the outer table and compression increases on the inner table as the bone bends inward (9). This causes concentric fractures to begin on the outer surface and travel inward, thus creating an internally beveled appearance (11).

In the case of gunshot wounds to the skull, concentric fractures are also known as heaving fractures, because the plates of bone are lifted upward by an increase in intracranial pressure. In the area of the concentric fracture production, tensile forces are increasing the inner surface and compressive forces to increase on the outer surface. This leads to concentric fractures, which fail on the inner table and travel outward, thus creating an externally beveled appearance (Fig. 9). Compressive and tensile forces occur on the same tables in exit wounds, which mean concentric fractures of exit wounds are also externally beveled (21).

Materials and Methods

The sample for this research consists of a combined total of 163 blunt force and ballistics trauma injuries from 120 skulls exhibiting concentric fractures (Table 1). Of these injuries, 79 were from blunt force trauma and 84 were from ballistics trauma. The analyzed specimens were reviewed from cases at the Shelby County Regional Forensics Center in Memphis, Tennessee ($N = 136$); the National Museum of Health and Medicine in Washington, D.C. (NMHM) ($N = 25$); and the Smithsonian Institution's National Museum of Natural History in Washington, D.C. (NMNH) ($N = 2$). All of the Regional Forensic Center cases came from skeletal remains retained as evidence in forensic cases (1983–2000). The collection from the NMHM included the Milton Helpern New York City Medical examiner's Collection (1940–1970). NMNH cases came from one skull from the Terry Collection (1921–1946).

Only wounds displaying concentric fractures were included. The types of weapons used in the blunt force trauma cases varied greatly and included kicks and punches (9), hammers (9), baseball bats (4 wounds), bricks (4 wounds), motor vehicle accidents (2), trains (2), steel girders (1), boards (1), and lead pipes (1). Eight blunt force trauma injuries came from unknown means. Calibers and gauges studied in the ballistics cases included shotguns (14), 9 mm (8), .38 (8), .357 (6), .40 (2), .45 (1), and other (1). Unknown weapons inflicted twelve of the ballistics wounds.

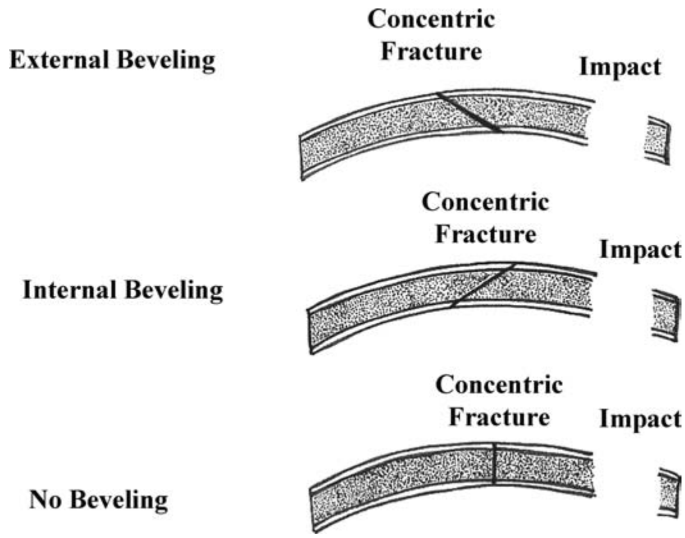

FIG. 10—*This diagram demonstrates the traits of external and internal beveling of concentric fractures as well as fractures exhibiting no beveling.*

Concentric fracture morphology was analyzed and exterior and interior fracture surfaces were used to determine the direction of beveling (Fig. 10). In a limited number of cases, beveling could not be determined. External beveling included any case where more of the outer table of the fracture surface was present than the inner table. Internal beveling was judged as the opposite. Lastly, cases exhibiting neither internal nor external beveling were classified as having no evident beveling. The hypothesis of this study is that blunt force and ballistics trauma can be differentiated by concentric fracture patterns. Conversely, the null hypothesis is that the mechanism of trauma is not associated with the direction of beveling.

Contingency tables were constructed to preliminarily test the null hypothesis of no association between the two variables (the mechanism of trauma and the direction of beveling). Pearson's Chi-square, performed in SPSS 9.0 (28), was used to test the statistical significance of the contingency tables. This test was performed on the entire sample, and then on fractures occurring in buttressed and non-buttressed areas. The contingency tables and chi-square tests are used to determine if a statistically significant relationship exists, but it is not a test of the strength of correlation (29).

Pearson's correlation coefficient (Pearson's r) was calculated to determine the strength of the relationship between the two variables (the mechanism of trauma and the beveling direction of concentric fractures). Pearson's r values that are close to –1 or 1 are determined to have strong relationships. The closer the r value is to 0, the weaker the relationship. Therefore, any value that is greater than 0.5 or less than -0.5, shows a predictability rate greater than chance allocation (29). Pearson's r was calculated for the total sample, and separately for the buttressed and non-buttressed areas using SPSS 9.0 (28).

Results

The total sample contingency table (Table 2) demonstrates a direct relationship between the beveling direction and the mechanism of trauma, since 73 of 79 cases of blunt force trauma are internally beveled, while 74 of 84 cases of ballistics trauma are externally beveled. The significance level of chi-square ($p = < 0.0005$) allows for the rejection of the null hypothesis (see Fig. 11).

TABLE 2—*Contingency table between trauma mechanism and beveling direction among the entire sample.*

	Blunt Force Trauma	Ballistics Trauma	Total (%)
Internal	73	0	73 (44.8)
External	1	74	75 (46)
Neither	5	10	15 (9.2)
Total (%)	79 (48.5)	84 (51.5)	163 (100)

TABLE 3—*Contingency table for isolated cases occurring in buttressed regions of the skull.*

	Blunt Force Trauma	Ballistics Trauma	Total (%)
Internal	48	0	48 (44)
External	0	48	48 (44)
Neither	5	8	13 (12)
Total (%)	53 (48.6)	56 (51.4)	109 (100)

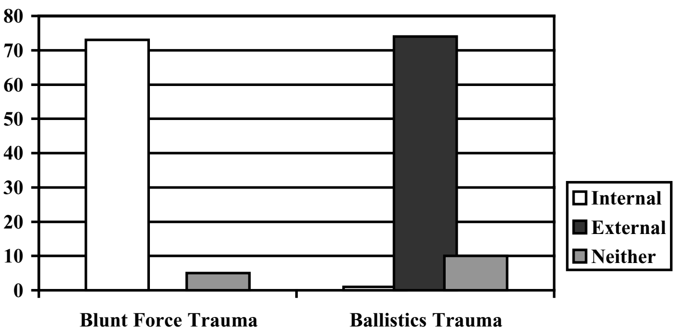

FIG. 11—*Bar graph of the relationship between beveling direction and the trauma mechanism in the entire sample.*

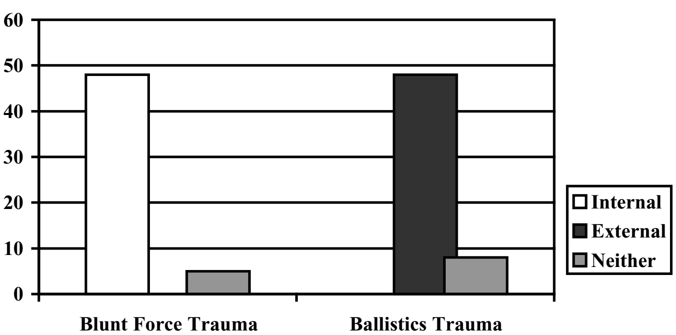

FIG. 12—*Bar graph of the relationship between beveling direction and the trauma mechanism in the buttressed sample.*

For the fractures in buttressed areas of the skull, the contingency table (Table 3) indicates the existence of a relationship between the variables. In blunt force trauma, 48 of 53 cases are internally beveled, and in ballistics trauma, 48 of 56 cases are externally beveled. The significance of the chi-square test result ($p = <0.0005$) allows for the null hypothesis to be rejected in cases in buttressed areas (Fig. 12). In cases occurring in non-buttressed areas, the contingency table (Table 4) shows a relationship between the two variables. Here, 25 of 26 blunt force trauma cases are internally beveled and 26 of 28 ballistics trauma cases are externally beveled. Furthermore, the significance of the chi-square test result ($p =<0.0005$) allows for the null hypothesis to be rejected (Fig. 13).

TABLE 4—*Contingency table for isolated cases occurring in non–buttressed regions of the skull.*

	Blunt Force Trauma	Ballistics Trauma	Total (%)
Internal	25	0	25 (46.3)
External	1	26	27 (50)
Neither	0	2	2 (3.7)
Total (%)	26 (48.1)	28 (51.9)	54 (100)

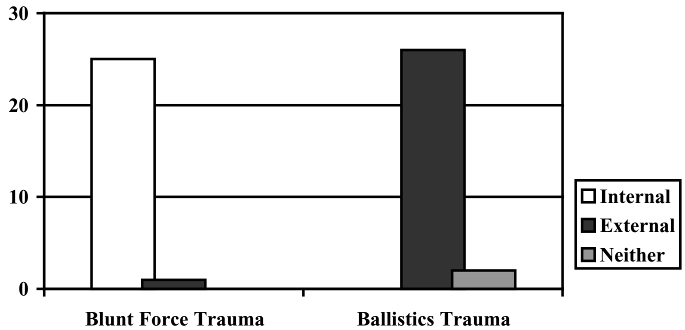

FIG. 13—*Bar graph of the relationship between beveling direction and the trauma mechanism in the non–buttressed sample*

Pearson's r was calculated as a descriptor of the degree of linear association between the two variables. In the entire population, Pearson's r value is 0.629, the Pearson's r value in buttressed cases is 0.563 and the value in non-buttressed cases is 0.720. The p values for all Pearson's r tests were <0.0005. A significant relationship was found to exist between the Pearson's r values in the entire sample as well as the buttressed and non-buttressed areas. This relationship is stronger than chance allocation.

Conclusion

The results of this study suggest that the mechanism of trauma may be determined by the direction of beveling in concentric fractures. Cranial concentric fractures associated with blunt force trauma are internally beveled, whereas concentric fractures resulting from ballistics trauma are externally beveled. The contingency table and the Chi-square test performed on the entire sample displayed probabilities that are statistically significant, thus indicating that the null hypothesis is improbable. Similar results were produced when concentric fractures occurring in buttressed areas were isolated from concentric fractures occurring in non-buttressed areas. Therefore, the hypothesis that blunt force and ballistics trauma may be distinguished through the direction of concentric fracture beveling is supported.

The Pearson's r correlation coefficient was calculated to determine the degree of association between the two variables (the mechanism of trauma and the direction of beveling). A significant relationship was found among the total sample, in buttressed areas, and in non-buttressed areas. The strongest relationship was observed in non-buttressed areas (0.723). This suggests that there is a stronger relationship between the mechanism of trauma and the direction of concentric fracture beveling occurring in non-buttressed areas of the skull.

There are several areas that need to be further examined. This study examined fracture patterning of blunt force and ballistics trauma to the cranial vault, but no attempt was made to analyze the fracture patterning in the thin bones of the face. An additional area to be addressed in the future would be examination of cranial fracture patterning to juveniles and infants. The sutures of these age groups are not united, which would cause the bones of the skull to behave independently.

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