Resiliency in Cranial Bones in Relation to Age and Trauma

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The older an individual gets, beyond infancy, the more likely traumatic injuries resulting in bone mutilation will become fatal. Bone serves several processes within the skeletal system. Some of these functions may include movement, protection, the production of hormones, as well as, mineral and growth production storage (Betts et al., 2013). The properties of bones do not remain constant with age; rather, they change throughout life, in some cases improving in function, but in others, function deteriorates (Boskey & Coleman, 2010). As individuals get older, their bone density decreases for a number of mechanical and hormonal reasons, weakening the bone and increasing fragility. This decreased bone mass density, along with its increased risk of fragility, often lead to a higher likelihood of fractures and severe traumatic injuries; this combination of factors is a lot greater than in younger individuals. One of the major leading causes to this deterioration of bone mass is a result of osteoporosis. This disease can be found in men and women, usually over the age of 30. It often accelerates after menopause in women, and andropause in men (Villa-Forte, 2017). However, it is said that the skull is usually unaffected by this process due to different bone matrix characteristics due to differences in osteoblasts (Paddock,2009). Due to the structural differences between the bones of the skull and most other bones of the skeletal system, osteoporosis does not affect cranial bones. Even with that being stated, some of the same causes of osteoporosis may also lead to loss of bone mass density within cranial bones. Some primary causes for both situations include but are not limited to: loss of mineral intake or hormone imbalances, which can occur with increased age. Due to the maturation of bone and the deterioration over time, cranial resiliency should be highest in younger individuals compared to the resiliency of older individuals. This study will evaluate skulls thickness, cross referenced by age and sex, will determine resiliency in terms of the biological structure itself.

In this research, resiliency is defined as the ability to withstand any detrimental deviation from normal bone structure, and mass. Aging is one of the leading biological causes for said detrimental deviation. Despite the fact that males are shown to have an increased bone mass density compared to females, both biological sexes decline with increased age (A.L. Boskey & Coleman, 2010). Other factors such as geometry and bone mass distribution, trabecular bone microarchitecture, microdamage, increased remodeling activity, genetics, body size, environmental factors, and changes in bone mineral and matrix tissue properties also influence fracture risk (Paschalis et al., 2004). All of these things explain the reasoning for loss of bone mass but none explain how the structure of bone affects this. The composition of bone consists of:

> a composite material whose extracellular matrix consists of mineral, collagen, water, noncollagenous proteins (NCPs), and lipids in decreasing proportion (depending on age, species, and site). These components have both mechanical and metabolic functions. Each of the components in the organic matrix of bone influences the mechanism of mineral deposition. (Boskey & Robey, 2013)

Collagen is responsible for the elasticity of bone, while noncollagenous parts of bone establishes the rigidity of bone mass, creating a stiff structure. As we mature, the mineral densities within our bone changes. A specific change is the formation of collagen crosslinks, which are believed to alter collagen structure. This altering of structure can directly affect the bones' mechanical properties. Collagen crosslinks occur between two different categories of collagen within tissues and can be held responsible for the stiffening of collagen. The rate of cross-linking increases with age which contributes to change in bone tissue properties. In direct relation to the skull, the minerals within its bone matrix reform in a way that negatively affects strength and toughness;

Ultimately, decreasing resistance to fracture propagation (Boskey & Coleman, 2010). This results in a decreased rate of resiliency in older individuals as the bone weakens, due to lack of elasticity creating an inability to protect itself from certain traumas.

Although crosslinking is a direct cause in negating the effectiveness of collagen, external factors may play an equivocal role in the process. While this study does not intend to focus on the relationship between skin and bone, an important outcome stated in the *Aging and Sexual Differences of the Human Skull* touches on how the reduction of collagen in skin affects bone:

> Among the theories of bone remodeling, the Functional Theory correlates bone remodeling to response to demand. When the bone is submitted to traction by a hypertrophic muscle or subcutaneous fat distension, a local demand is generated and bone is produced in that area. On the other hand, continuous pressure on the bone (e.g., silicon chin prosthesis) or intense muscle, ligament or skin laxity, may lead to bone resorption (Toledo Avelar, Cardoso, Santos Bordoni, de Miranda Avelar, & de Miranda Avelar, 2017).

The journal by Alvelar et al (2017), focuses primarily on sexual dimorphism of skull resorption, but it also depicts various parts of the skull that is resorbed due to increased age. The maxilla is more anterior and more prominent in younger skulls, whereas in older skulls an anterior and inferior bone resorption takes place, giving the appearance of a retrusion of the face (Toledo Avelar et al., 2017).The maxillary medial/orbital medial ratio increases when aged less than 20, furthermore from 20-50, and then begins to decrease when older than 50 (Avelar et al, 2017). Additionally, the mandible becomes less vertically projected which makes it more fragile (Avelar et al, 2017). The angle of the mandible increases due to muscular atrophy because of the absence of teeth, which also occurs with increased age (Avelar et al, 2017). This constant

resorption of facial bone within the skull is largely dependent on bone volume size or changes throughout a lifetime (Avelar et al, 2017). These are often an effect of aging and trauma; these changes result in decreased bone support (Avelar et al, 2017). Because this does not occur in younger individuals, the resorption of bone is a major factor of decreased cranial resiliency in older individuals. This decline in bone mass allows the skull to be more susceptible to direct trauma, and more likely for trauma to be significant.

In research conducted by Elizabeth M Lillie et al (2016), it was found that cortical thinning in the frontal, occipital, and parietal bones occurred within women 20-100 years old, 36-60%. However, males exhibited no significant changes, other than continued thickening of the mastoid process (Lillie et al, 2015). In females, the thickness of the parietal bone ranged highest at approximately 5mm, at relatively 37-39 years old. In males, parietal thickness generally ranges from 1.5-3mm from ages less than 20 to approximately 81, with an outlier at 60 years old and a 4.5-5 mm thickness (Lillie et al, 2015). From this research it is concluded that women over the age of 55 were at a significantly higher risk of mortality of a traumatic brain injury compared to any other group (Lillie et al, 2015). This could be a likely cause of the onset of menopause that contributes to an increase in bone mass deterioration. Women lose about 50% of their trabecular bone and 30% of their cortical bone during the course of their lifetime, about half of which is lost during the first 10 years after the menopause. (Finkelstein et al., 2008)Approximately 40% of all postmenopausal women will eventually experience fractures(Finkelstein et al., 2008).

Morphological changes in cranial bones demonstrate significant change with increasing age (Urban et al, 2014). In research completed by Jillian E Urban et al (2014), evaluations of morphological changes in the skull were used to determine where on the skull sexual

dimorphism was most prominent, so the information could identify landmarks for age determinants. In males, most significant changes with age were found on the outer cranial vault, inner cranial vault, anterior cranial fossa and middle cranial fossa. In females, the most significant shape changes with age were found within the anterior cranial fossa and middle cranial fossa. Although the research never blatantly states that these changes increased with age, there is enough information to support this cause. The information stated supports the hypothesis that higher cranial resiliency occurs in younger individuals because it is pinpointing which areas would be most likely to withstand trauma.

Another important factor that affects cranial resiliency would be the effect of hormonal changes that can directly affect thickness of the skull. Four main hormones that affect osteoclastic bone resorption include calcitonin, parathyroid hormone, calcitriol—also called vitamin D, and estrogen (Lillie et al, 2015). The calcitonin and vitamin D help regulate bone density by stimulating osteoblastic activity. Vitamin D deficiency can lead to diseases based on defective mineralization, called rickets in children and osteomalacia in adults.(General (US), 2004) Treatment with vitamin D can restore calcium supplies within the body and reduce bone loss (General (US), 2004). Calcitonin is important during developmental stages in life because it is responsible for maintaining healthy bone development(General (US), 2004). Parathyroid increases osteoclastic activity and if estrogen decreases there is a loss of bone density. In spite of its detriment to bone density the parathyroid hormone increases with age and contributes to long lasting bone density reduction (Lillie et al, 2015). On the same hand, due to other hormonal changes estrogen tends to decrease with age (Lillie et al, 2015). Overall, bone density in women tends to decrease overall with age, decreasing possible pliancy. Cortical bone regressions in

women provide a significant relationship between decreased thickness and age of the cranial vault (Lillie et al, 2015).

Methods and Materials

This study will include approximately 10-20 skulls varying in post mortem ages to be examined. Ideally, the age ranges will be some less than 12, 20-30, 30-40,40-50 and then older than 50. These ranges will be beneficial to note the morphological change differences the skull faces with increased age. Along with age, the range of biological sex may provide additional information but may not inherently be explicitly beneficial. Previous research did not report skull changes within male and female sex categories, therefore it is not necessary to create an additional demographic variable to test them. At bare minimum, the differences in biological sex will only prove or disprove different ways cranial resiliency is highest in younger individuals. To implement this, the study will focus on measuring cranial thickness on different regions of the skull.

Standard calipers, will be used to measure the thickness of the outer cortical, inner cortical, and diploe on different sites of the skull. To be specific, the study will include the measuring the thickness of the frontal, parietal/temporal, and occipital bones, as similarly done in research by Lillie (2015). The skull will be sectioned into 4 quadrants, pinpointing the anterior, posterior, left, and right sites; by creating this 4-quadrant division, the measurement of each portion of bone will be collected. *(Figure 1)* Through the use of spreading calipers, the measurement of flat bone fragments will also be collected. By using the same method of a 4-quadrant division, but additionally using the longitudinal medial line, the differences in thickness along the line will be collected. This measure of thickness will help determine specific morphological structures and change in structures that affect resiliency. My examination of

resiliency will solely be based on prediction from the information collected and from previous research.

Results

The purpose of this study was to determine resiliency of skulls based on the thickness of cranial bones. The divisions of the skull are presented in *Figure 1* and *2.*

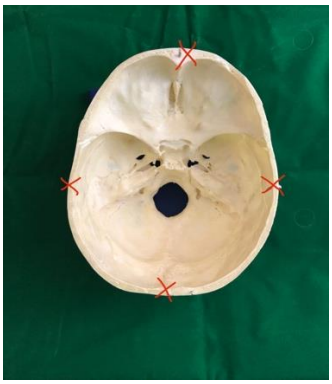

Figure 1. The original four sites on the crania.

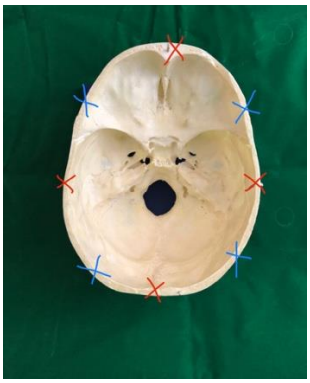

Figure 2. The secondary divisions of the crania, indicated by the blue x's.

For this portion of the research a formula was conducted to measure the thickness of the crania in millimeters. The formula is as follows: (Inner Cortical + Outer Cortical)/(Diploe). If the answer to that formula was less than 0, the diploe of the crania was thicker than the cortical layers combined. By applying this formula to all 8 sites on the skull, the average was calculated, and the order of average thickness is displayed in the in *figure 3.* The ages of the crania used during this research is presented in *figure 4.* A significant finding during this portion of the research was that Crania B was found to be the thickest skull, disregarding that it was the second oldest skull in the study. The rest of the proceeding crania thickness was Crania A, Crania E, Crania D and lastly, Crania C. Another interesting find within this research was that the Left, and Right-Parietal were found to be the thickest sites on the crania. Contrastingly, the Anterior and Right-Anterior were found to be the overall thinnest sites on the crania.

	Averages of Crania
Crania A	0.92507124mm
Crania B	0. 93278859mm
Crania C	0. 25548052mm
Crania D	0.37107597mm
Crania E	0.60521547mm

Figure 3. The averages of the sites of each crania measured in mm.

Ages of Crania	
Crania A	30-40 y
Crania B	45-50y
Crania C	50 (45-50) y
Crania D	42-47 y
Crania E	40 (37-40) y

Figure 4. The ages of each crania within the study.

The comparison for thickness of each site on all crania collected is found in *figure 5*; followed by the numerical values rounded to the ten thousandths place for each site in *Figure 6*. For accuracy, the height from each specific site on each cranium was recorded and is shown in *Figure 7.* To specify, the height of the left site was taken from either a small hole within the skull or a at the bottom of a screw placed within the skull for anatomical teaching reasoning; in comparison the right site was taken from the bottom of the screw on the right side of the skull. Continually, the height of the anterior site was taken from the naison. Lastly, the height of the posterior site was taken from the most posterior, inferior portion of the foramen magnum.

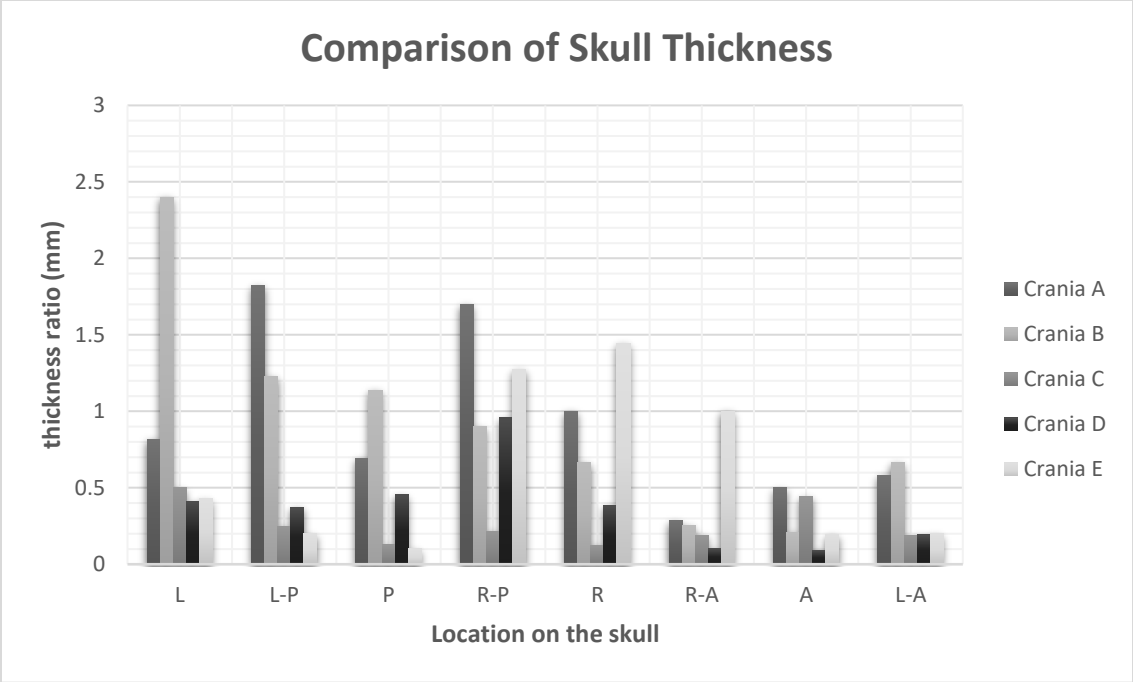

Figure 5. Comparison of each designated site on the skull to measure thickness.

	L	L-P	P	R-P	R	R-A	A	L-A
Crania A	0.8182mm	1.8235mm	0.6944mm	1.7000mm	1.000mm	0.2830mm	0.5000mm	0.5814mm
Crania B	2.4000mm	1.2273mm	1.1385mm	0.9000mm	0.6667mm	0.2545mm	0.2087mm	0.6667mm
Crania C	0.5000mm	0.2500mm	0.1290mm	0.2174mm	0.1250mm	0.1905mm	0.4444mm	0.1875mm
Crania D	0.4091mm	0.3712mm	0.4545mm	0.9583mm	0.3846mm	0.1053mm	0.0930mm	0.1923mm
Crania E	0.4286mm	0.2000m	0.1017mm	1.2727mm	1.444mm	1.000mm	0.1943mm	0.2000mm

Figure 6. Numerical values of thickness for each site on the crania within the study.

	Height of Left	Height of Parietal	Height of Right	Height of Anterior
Crania A	55.8mm	96.3mm	61.6mm	40.3mm

Crania B	35.7mm	72.5mm	30.2mm	14.5mm
Crania C	3mm	88.9mm	7.2mm	30.4mm
Crania D	6.4mm	75.4mm	6.8mm	40.8mm
Crania E	77.9mm	97.8mm	75.4mm	18.5mm

Figure 7.The height from each designated site on the crania, measured in mm.

The key findings from this research was that the thickest skull in the study was not the youngest skull. However, the oldest skull was the thinnest, therefore, the least resilient to sustain trauma. According to the findings of this research the anterior portion of the skull showed the most weakness.

Discussion

In this research it was not expected to find that the second oldest skull within the sample size would be the thickest and consequently most resilient. Momentarily disregarding Crania B, the following craniums measured in thickness as predicted. The younger skulls proved to be more resilient in thickness than those that were older within the study. Additionally, if faced with certain traumas the younger skulls would prove to be more resilient and less likely for the trauma to be fatal. It is also important to note that Crania B may be an outlier for its age range. Additionally, the sample size was considerably smaller than expected and that affects the results by giving a more narrow outcome. The projected sample size was 10-20 skulls varying in age ranges to adequately test the change in thickness throughout the skull. However, due to time constraints on the experimental portion, the sample size gathered consisted of 5 skulls ranging in the ages of 30-50 years old. Due to a narrowing of the projected age range, the information

collected specifically focuses on changes within that occurred within 30 to 50-year constraint. The projected outcome may have varied with a larger test group varying in a larger age range.

All skulls used were anatomically cut through the superior portion of the crania, exposing the inner and outer cortical, as well as, the diploe in between these layers. A standard dial caliper was used to measure the layers of each crania. A confounding variable that could have a large effect on the results of the research may be a result of human error. The measurements that were collected, were judged by sight, specifically of where one layer began and another ended. Another possible confounding variable could have been differences in decomposition of bone, it is possible that not all of the skulls used in the research were equivocally preserved resulting in deterioration of bone postmortem.

Surprisingly, there were no significant sites on the skull that demonstrated overall thickness based on age alone. To further explain, for the younger crania within the study there was no site that presented a larger difference in thickness compared to the older skulls. The sites found to be most thick or most thin were found throughout the majority of the skulls and therefore cannot be a younger skull trait. The older skulls proved to be less resilient based on a decreased thickness throughout the entire skull. However, even with those findings to support the hypothesis, the differences were not as large as expected.

Some recommendations based on the finding of this research for any possible future directions would be to firstly, test crania against different formulas for thickness. The formula used for thickness may not have been the most accurate way to determine overall thickness in crania based on the layers of the skull. Having a larger diploe, versus a combination of cranial cortical layers may not necessarily result in a thicker bone mass overall. Secondly, measuring the thickness of bone layers by sight and by hand can present an opportunity for greater error,

consequently leaving opportunity for affecting data and the results. If there was a way to test thickness of crania bone layers within under a microscope it may be easier to efficiently differentiate those layers.

Conclusion

Based on the findings within this research, an efficient way to measure cranial thickness based on age and biological structure can be concluded. It was hypothesized at the beginning of this research that cranial resiliency should be highest in younger individuals compared to older individuals. Although, the skull with the overall greatest thickness was the second oldest, which does not support the hypothesis the order of the remaining skulls demonstrate that the older skulls were weaker. By using the thickness formula, formulated during this research it is possible to determine thickness of a cranial bone based upon the differing layers.

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