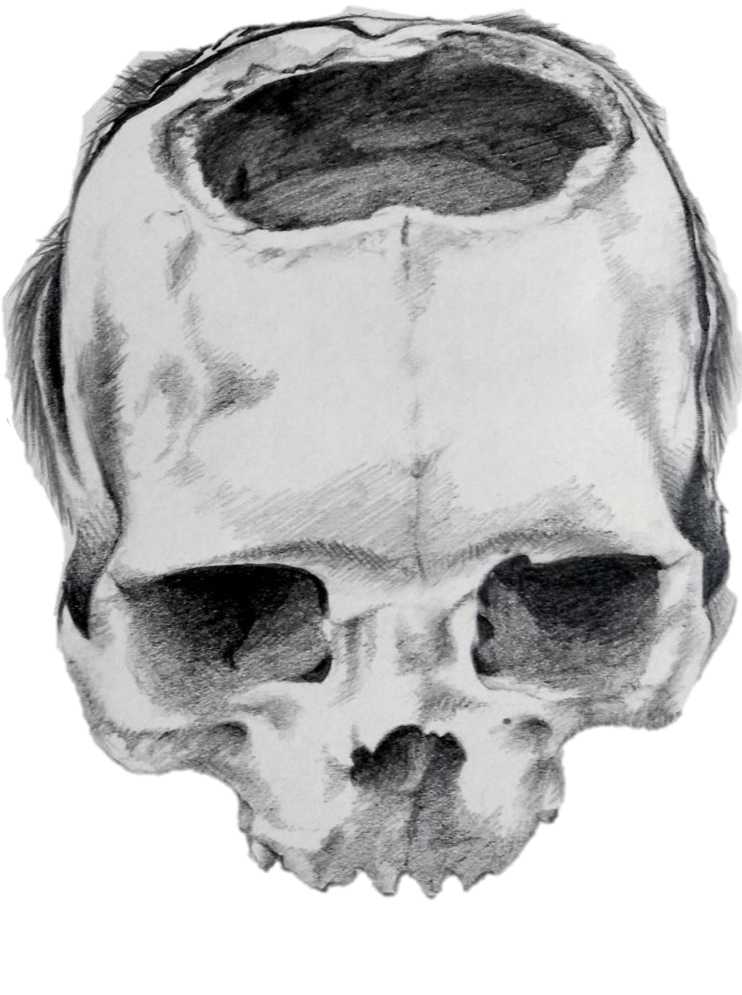
Living with Holes in the Head:

A regional study on the nature and survival rates of trepanation in Pre-Colonial Peru



Jennifer Stacey s1829424

Figure 1: A pencil drawing depicting a large trepanation, found in Paracas on the south coast of Peru. Held at the Museo Nacional de Antropología, Arqueología, y Historia, Lima, Peru (Stacey 2019).

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Table of Contents

1. Introduction

1.1. Defining Trepanation

This thesis aims to define the characteristics of trepanation in Pre-Columbian Peru, as well as the survival rate of this procedure. Trepanation, or trephination, is the act of creating an opening in the cranium vault. It is a form of cranial modification which has been found in areas around the world with similar diagnostic features (Verano 2016, 1). Peruvian individuals have been found with deliberate cranial trauma for over a century (Fernando & Finger 2003, 3; Heaney 2018, 350) and this has been the subject of many theories – from ritual to ancient surgery.

Trepanation is interesting to study because it can enable us to understand more about a Peruvian practice whose history has been overlooked. Since the Spanish invasion, the practice was almost entirely distinguished within Peru, and not written about. The existence of Peruvian trepanation was only considered by scholars after evidence was found of deliberate cranial hole-making within Neolithic Europe. Because of this, it is important to utilise the archaeological evidence available to us in order to learn about this forgotten practice. Unfortunately, few region-wide studies have been performed on this subject, and survival rates have often been published on small sample sizes. This thesis will combat this by combining these studies to create an overview of the practice.

1.2. Trepanation in Peru

Trepanation is a phenomenon that appears regions and decades apart. The etymology of the word "*trephination"* has lingual roots from Ancient Greek society. The word is a derivative from the term for "borer" (*trypanon),* in which the instrument would be the "*trepan*". Since recent times, it has been understood that the practice of trepanation has a history in both the Western and Eastern parts of the world – existing in parts of China (Hobert & Binello 2017, 451; Lv *et al.* 2013, 897), regions of Neolithic Europe (Bennike 2003, 95; Nicklisch *et al.* 2018, 216; Prioreschi 1991, 296), the Mediterranean (Crubézya *et al.* 2001, 417; Riccomi *et al.* 2017, 9), Russia (Gresky *et al.* 2016, 665), North Africa (Nikita 2013, 370), the Near East (Erdal & Erdal 2011, 505), North America (Stone & Miles 1990, 1015), Central America (Wilkinson 1975, 838) and other parts of South America besides Peru (Gomez 1973, 585). While death may be an expected result of this practice, many cases show that it is possible to survive the procedure. This is shown through ancient cases of healing. Surviving a trepanation would involve the opening of the scalp layers and the cranial vault, producing a highly hazardous lesion to care for. After this, infections are of an increased likelihood due to the extensive and constraining healing process an individual must go through. Despite this, long-term survival has been shown to be possible in pre-Columbian Peru.

The history of research on Peruvian trepanation originated in the 19th century. In 1865, Ephraim George Squier obtained an ancient Peruvian skull, which is known as one of the most prominent examples of "ancient trepanation" (Fernando & Finger 2003, 3; Heaney 2018, 350). Paul Broca, a focal figure in anthropology and a practicing surgeon (Fernando & Finger 2003, 9) believed this skull was evidence of an ancient surgical operation, enacted without associated fractures. This idea provoked the anthropological community, and in turn, launched the study of European Neolithic trepanation (Heaney 2018, 350). In 1893 another surgeon, Manuel Antonio Muñiz, convinced many at the Congress of Anthropology that his collection of skulls proved that ancient Peruvians had the expertise in surgery of a similar, if not superior, level to 19th century Europeans (Heaney 2018, 353). For some time, the celebration of pre-Columbian trepanning, and their assumed expertise, continued. Another figure, McGee, voiced a different interpretation that Muñiz' collection showed the result of "ignorant", "skilless" quack healers (Heaney 2018, 353). It was then anthropologists, like Julio Tello, who spent a decade attempting to deconstruct this narrative of Pre-Columbian incompetence (Heaney 2018, 358).

While research has been done on Peruvian trepanation, the area of interest is lacking in region-wide data on the characteristics and survival rates of Pre-Columbian trepanation, of which this thesis aims to provide. This is important for two reasons; it provides evidence on past scientific knowledge, and it enables us to re-evaluate our preconceptions about the ancient practice.

Firstly, speculation about past scientific knowledge is a topic that many commonly associate with anthropology and the study of human progression. It is therefore of interest to look at the survival rate of such an invasive surgery. Doing so can determine whether specialised knowledge of cranial anatomy and infection was understood in order to guarantee survival. In regards to the history of surgery, ancient cases of trepanning in Peru have been discussed as being the "first sources of industry, the sciences and the arts" in America (Fernando & Finger 2003, 11).

Secondly, by studying the characteristics and the survival rate of trepanned individuals, it is possible to deconstruct and objectively re-evaluate our perceptions of pre-Colonial surgery. Due to cultural and generational biases, Peruvian cases of ancient cranial modifications have led some Western scholars to assume it was a ritual, "primitive" act done with little awareness of cranial anatomy (Fernando & Finger 2003, 14). However, more recent studies have begun to disprove this theory, finding higher survival rates than expected. Post-colonial archaeology – a fairly recent development in the field – has aimed to "reconsider colonialism from the perspective of colonized peoples and their cultures" and thereby "revealing its continuing ramifications in the present" (Lydon & Rizvi 2010, 19). It connects the way we think about pre-Colonial cultures in the present, with their colonial past as the focal point. Through this theoretical standpoint, there is an opportunity to legitimately counter the historically-negative view of early surgery in Pre-Columbian Peru.

1.3. Aims & Research Questions

The aim of this thesis is to study trepanation from a holistic and post-colonial perspective. This will be done by answering two research questions: what are the characteristics of trepanation in Pre-Columbian Peru, alongside what the overall survival rate is of the trepanned individuals? These research questions contain further sub-questions that take into account the regional differences of trepanation as a potential variable of the survival rate and its characteristics.

1.3.1. What were the characteristics of trepanation in Pre-Columbian Peru?

Firstly, this thesis will address different characteristics of the procedure from various articles and sources. It will be further categorised into sub-questions on the methods used and the individuals themselves.

- *What techniques were used?*

The question of what techniques they used will involve any archaeological evidence of pre-surgical and post-surgical treatments that were used on the patient. It will also include the method used to create the hole in the skull; being either scraping, circular grooving, linear cutting or boring. This may provide an overview of the methods used most frequently, and whether it was likely to have influenced the survival of the individual. The frequency of unknown methods will be taken into account, and will aim to give further context to the rate of healing.

- *Where on the cranium were they performed?*

The location of the cranial vault will be looked at in relation to the left or right side of the head, as well as the placement of the hole in relation to the anterior, posterior or superior position.

- *Who were trepanations performed on?*

The biological profiles of those in the trepanned sample will be assessed, including the estimated frequencies of males, females and those of indeterminate sex. In addition to this, age-at-death estimations will place individuals within age-groups, including subadults (below 17 years old), young adults (18-25 years old), middle adults (26-45 years old), older adults (older than 46 years old) and the adult group (an unknown adult age category).

- *How many trepanations per individual occurred?*

The frequency of holes per individual, from the occurrence of 1 to above 4 trepanations will be calculated for the regions where this information is supplied. The phenomenon of multiple trepanations had led to a larger sample size of trepanations than individuals.

1.3.2. What is the survival rate of trepanation in Pre-Columbian Peru?

The second question aims to define the rate of healing, and the rate of survival. For this, the survival criteria will be laid out clearly, discussing the healing process after trepanation and establishing what the varying levels of survival are. Risks that were present during the surgery and during the healing process will also be discussed as it may have affected the overall survival rate. Survival rates will be comparatively shown by their region in aims of finding patterns within the survival rates. Correlations with the method and location will be discussed, in order to broaden the understanding of the survival rate.

1.4. Approach & Materials

The discussions and conclusions of the nature and survival rate of trepanations will be founded in data in order to produce an objective answer. The data that will be used in this thesis is secondary, meaning the data used had originated from the results within published articles. The presentation of each article's data is not consistent in the way of detail and depth, and therefore poses certain difficulties when it comes to quantifying and comparing data (tab. 1). This will be dealt with by having different sets of comparison groups for each variable tested. The data will be taken from six articles, ranging in sample size, region and period – including an MNI (Minimum Number of Individuals) of all crania observed in each study.

Table 1: Availability of trepanation characteristics within the six sample studies.

	Andrushko & Verano (2008)	Kurin (2013)	Nystrom (2007)	Rogers (1938)	Toyne (2015)	Zimmerman *et al.* (1981)
Time period	✓	✓	✓	✓	✓	✓
Cranial MNI	✓	✓	✓	✓	✓	✓
Trepanned Individuals	✓	✓	✓	✓	✓	✓
Position on the Skull	✓	x	✓	x	✓	✓
Method of Trepanation	x	✓	✓	✓	x	✓
Number per Individuals	✓	✓	✓	x	x	✓
Age Estimation	✓	✓	✓	x	✓	✓
Sex Estimation	✓	✓	✓	x	✓	✓
Healing Stage	x	✓	✓	✓	✓	✓

The sample group of crania used in this thesis were found in different areas of Peru and date to different archaeological periods. While many collections of ancient Peruvian skulls have been documented and published, there are likely collections that will not be included in this study – either because they were not accessible or because they were not published at the time. It is with some difficulty that as many studies as possible have been incorporated within the results, in spite of the of data presentation. As the samples were found in different areas of Peru, areas will be separated according to their 'department'. This term is used because it combines the locations of archaeological sites with the current-day '*departmentos',* existing to demarcate governmental constituencies. The samples cover four departments of Peru (fig. 2), Amazonas, Cusco, Apurímac and Lima

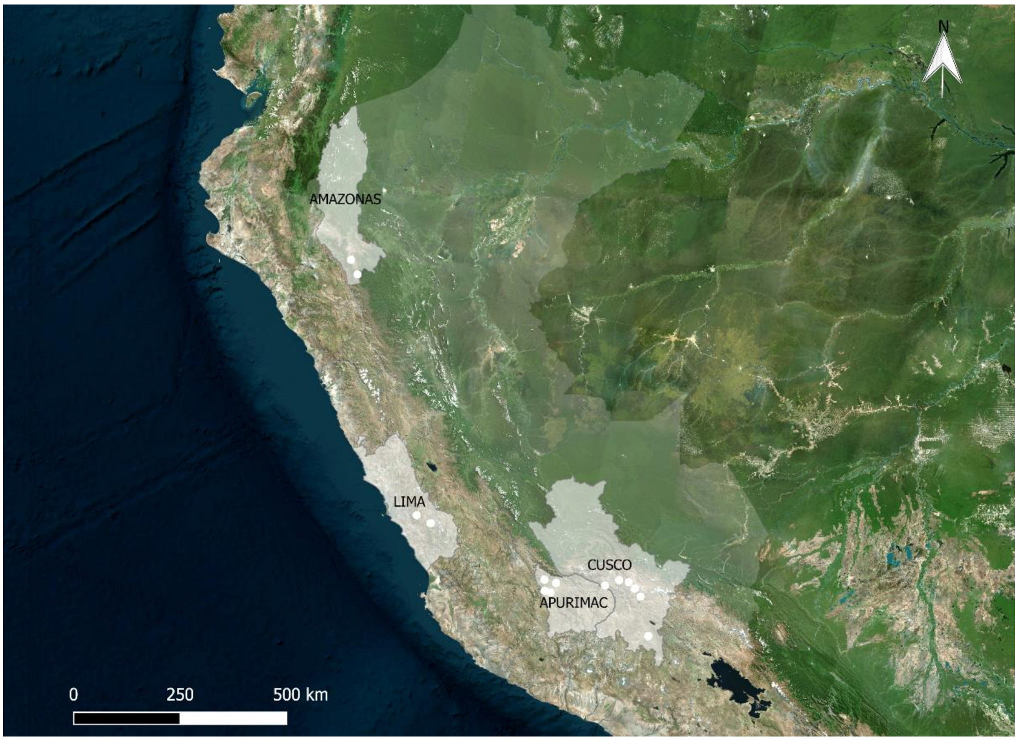

Figure 2: Map of departments in Peru which are represented in the sample (Stacey 2019).

The sample crania date to the archaeological periods of Middle Horizon (A.D. 600-100), the Late Intermediate Period (A.D. 1001-1476), Late Horizon (A.D. 1477-1531) and the Early Colonial Period (A.D. 1532-1633). This selection of data enables a broad area of the country to be covered, representing at least one time period within a sample.

It is important to establish consistency when quantifying the survival rate of the procedure from skeletal remains. Therefore, a scoring system with three categories will be determined, and discussed in detail within the chapter about survival rates. It will be comprised of three levels; '0' indicating either post-mortem trepanation or immediate post-operative death; '1' indicating postponed post-operative death and '2' indicating prolonged healing with extensive bone growth.

1.5. Thesis Outline

The second chapter of this thesis is reserved for providing contextual information about the six studies which data has been extracted from for this research. The departments as well as an overview of the archaeological context of the studies will be discussed.

The third chapter begins with tackling the nature of Peruvian trepanation as recorded from the sources used. The chapter will address the methods and techniques used, as well as their frequencies in the skeletal samples. Other factors of location on the cranial vault and the frequency of holes made will be noted. Finally, the biological profiles of the trepanned individuals will be compared between areas, sexes and ages.

The fourth chapter aims to address the focal point of the thesis, being the survival rate from the gathered data. It will address the survival criteria in place in more detail. Within this, the final figure of the overall survival rate will be created, along with other figures based on the survival rate per department and the technique used.

The fifth chapter will be comprised of the discussion of the results. The potential confounding factors in this study, such as the phenomena of pseudo-trepanation and sample issues, will be discussed. Further comparisons between the results of this study and those from trepanation studies originating from Italy, Anatolia, Southern Russia, Britain and North America will be highlighted. The theorised reasons around trepanations in Ancient Peru will also be addressed to add context to a part of the study which cannot be investigated, but lends itself to the discussion of the nature of trepanations.

The sixth chapter is where the final conclusions to the research questions will be presented. Results for the survival rate and the nature of trepanation will be presented from substantiated analysis in the previous chapters. Any problems that were encountered will be noted, along with possible improvements that could be made if the research is conducted again. Insights into further research which can be conducted in this area will be suggested.

2. Context & Archaeological Background

2.1. Archaeological Periods

This chapter will give a short history of Peru over the period of A.D. 600 to 1633. It was during this time span that the majority of trepanned crania were dated to in this region of the world – and therefore makes it relevant to briefly understand in terms of societal development. After this, the archaeological context will be given for each department of Peru that will be discussed. More information about where the studies' data came from and how it was extracted is explained.

The periods include the Middle Horizon (MH), the Late Intermediate Period (LIP), the Late Horizon (LH) and the Early Colonial Period (ECP) (tab. 2). "Horizon" periods categorise themselves as times of political control by a certain authority, whilst the "Intermediate" periods are fragmented times following the decline of power. The Middle Horizon (A.D. 600-1000) saw the advance of both the Wari and Tiwanaku culture. The Wari 'ruled' over the majority of Peru through a "network of regional administrative centers" (Jennings 2006, 265). The Tiwanaku culture brought new agricultural developments and religious iconographies to areas of Peru (Henderson 2013, 23). The Late Intermediate Period (A.D. 1001-1476) saw the fragmentation of Wari influence and created a "political vacuum" that created social instability through much of Peru (Kurin 2013, 485). This meant new polities could develop, creating "high levels of competition and warfare" (Conlee 2003, 47). By the Late Horizon (A.D. 1477-1531), new powers emerged, with the most notable being the Inka Empire. The Inka forced the narrative that Peru was a "primitive void" before the Inka people brought civilisation – however it is now seen that the Inka Empire was mostly a culmination of Andean traditions (Henderson 2013, 31). Although, by providing new agricultural technology, an improved system of state formation, and provided new religious ideology (Henderson 2013, 32) they unified what was once a fragmented region. This did not stop the conflict between the Inka Empire and the Spanish when contact was made, and due to these differences, instances of trepanned skulls sharply diminished at the presence of European contact in 1532. There is one Early Colonial Period trepanation present in the sample (Zimmerman 1981, 499), however it is likely this is an isolated example within its time period (A.D. 1532-1633).

Table 2: Table displaying the sites from the multiple studies used as data in this thesis, including where they are located in modern day Peru (since 2002) and the archaeological periods they date to. (MH = Middle Horizon; LIP = Late Intermediate Period; LH = Late Horizon; ECP = Early Colonial Period).

Publication	Sites	Cranial MNI	Trepanned Individuals	Modern Department (since 2002)	Time Period
Nystrom 2007	Kuelap	97	**8**	Amazonas	LIP
	La Petaca	3	**3**	Amazonas	LH
Andrushko & Verano 2008	Qotakalli	195	**34**	Cusco	LIP
	Chokepukio	83	**7**	Cusco	LIP
	Colmay	59	**21**	Cusco	LH
	Cotocotuyoc	35	**2**	Cusco	LIP
	Aqnapampa	21	**1**	Cusco	LIP
	Kanamarca	18	**1**	Cusco	LH
Kurin 2013	Cachi	162	14	Apurímac	LIP
	Ranracancha	39	6	Apurímac	LIP
	Pucullu	31	5	Apurímac	LIP
	Natividad	24	**7**	Apurímac	LIP
Toyne 2015	Kuelap	214	**7**	Amazonas	LIP-LH
Rogers 1938	Cinco Cerros	4800	**59**	Lima	MH
Zimmerman *et al.* 1981	Llactashica	1	**1**	Lima	ECP
	Total:	5782	**176**		

2.2. Context of Materials

This sub-chapter aims to describe the context of the research in which the sample data originated from. It will explain where the crania were found, as well as the extent of detail published about them, such as whether sex and age-at-death was estimated and recorded. This is important as each study will not be used equally, and its importance in this thesis will be determined by how much detailed data has been published. After being introduced, these sites are separated by the modern departments they are located in, and further context is given.

The first four articles describe the sample crania in extensive in detail, including sex, age-groups and location on the cranium. This includes Nystrom's 2007 study and Toyne's 2015 study from the Amazonas department (Nystrom 2007, 39; Toyne 2015, 30), Andrushko & Verano's 2008 study (Andrushko & Verano 2008, 4) from the Cusco department and Kurin's 2013 study from the Apurímac department (Kurin 2013, 484). The sites in these studies where no evidence of trepanation was found will be excluded from the cranial MNI. Three of the studies (Kurin 2013, Nystrom 2007 and Toyne 2015) have the capabilities for correlation analysis on age, sex, number, location and method. This will be used when discussing the survival rate and which variables likely affected it. The remaining two studies will be included to a certain extent, as they do not describe their samples in as much detail or have a very small sample size. This group includes Rogers' 1938 study and Zimmerman *et al.*'s 1981 study in the Lima department (Rogers 1938, 321; Zimmerman *et al.* 1981, 497).

2.2.1. Apurímac Department

Kurin's 2013 study attempts to link the appearance of trepanation with violence in the Late Intermediate Period. The skeletal series used in the study were found at the sites Turpo, Cachi, Ranracancha, Pucullu and Natividad (fig. 3). All of these sites, except Turpo, showed evidence of trepanations – therefore Turpo was excluded from the sample in this thesis. All sites, except for Turpo, dated to the Late Intermediate Period, and came from both tombs and cave ossuaries (Kurin 2013, 485). The recovered crania were all located in the department of Apurímac, and their sex and age-at-death was estimated. Trepanation methods were examined, as well as their state of healing.

2.2.2. Cusco Department

Andrushko & Verano's 2008 study focuses comparing sites with and without instances of trepanation in Cusco, and attempts to link survival through the trepanning process with its purpose as a surgical method. To do this, the study uses skeletal remains from six Cusco area sites (fig. 3); Qotakalli, Chokepukio, Colmay, Cotocotuyoc, Aqnapampa and Kanamarca – all of which have instances of trepanation. Archaeologically, each site seemed to have served a "variety of functions" (Andrushko & Verano's 2008, 5) such as residential, storage and burial use. The remains from these sites range from the Late Horizon to the Late Intermediate Period. Sex and age-at-death was estimated, and the method of trepanation was examined. The state of the perforations were assessed for

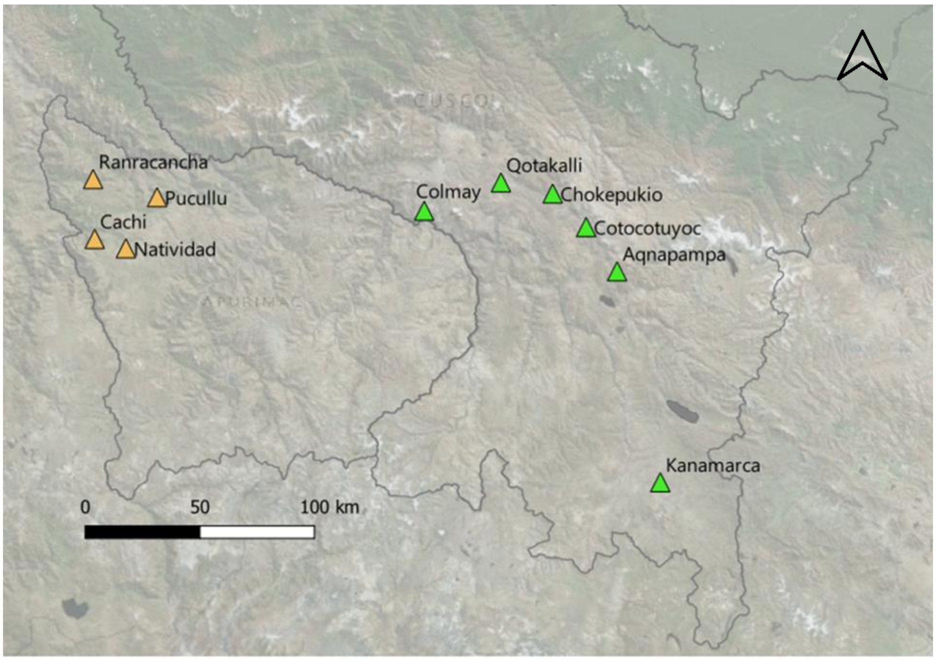

Figure 3: Map of Apurímac and Cusco. Apurímac: (orange) Ranracancha, Pucullu, Cachi and Natividad. Cusco: (green) Colmay, Qotakalli. Chokepukio, Cotocotuyoc, Aqnapampa and Kanamarca (Stacey 2019).

evidence of healing. Photographic evidence of some of the skeletal remains are published, including healed and unhealed trepanations.

2.2.3. Amazonas Department

Toyne’s 2015 study is based on a skeletal sample from Kuelap (fig. 4). The chronological separation of the burials were not refined, but are mostly dated to the Late Intermediate Period and Late Horizon (Toyne 2015, 32). Kuelap is described as an “urban architectural complex” which featured stone circular structures for residential, religious and administrative use. It included burials within the city, such as the cliff-side “mortuary structures” (Toyne 2012, 32). The study’s focus was not to identify evidence of trepanation at Kuelap, but to identify several types of cranial lesions. One of the reoccurring lesions proved to be evidence of trepanation, with other associated cranial traumas. Likely due to this, the method of trepanation was not noted. However, four out of the seven trepanations are photographed and therefore identifying the method of trepanation is possible. The preservation of the crania varied from poor to very good, despite this, the individuals’ sex and age-at-death were estimated (Toyne 2012, 32).

Nystrom’s 2007 study examined skeletal series from four sites, Kuelap, La Petaca, Laguna Huayabamba and Los Pinchudos – all of which are located in the department of Amazonas. Two of these sites, Laguna Huayabamba and Los Pinchudos, will be excluded from the sample as no instances of trepanation were identified by Nystrom. The Kuelap sample was collected during an archaeological survey by Henry and Paule Reichlen in 1950 (Nystrom 2007, 40) and is separate from the sample in Toyne’s article as they date to the Revash series. It includes skeletal remains from three occupational phases at the site of Kuelap (fig. 4); the Kuelap, Chipurik and the Revash phases. This provides a ranging date (1000-1470 A.D) that falls within the Late Intermediate Period. It is stated in the article that the archaeological context of the skeletal remains is not known, but based on the writing of Reichlen, it is assumed they were found within the city of Kuelap (Nystrom 2007, 41). The skeletal sample from the site of La Petaca (fig. 4) is from an isolated collection that was housed at the *Instituto Nacional de Cultura Museum* (Nystrom 2007, 43). Again, there is limited contextual information known about this collection, besides the ambigious fact it was found at a "cliff-side" burial site called La Petaca. It is probable to date to the Late Horizon, with some pre-Inca elements (Nystrom 2007, 43). The study estimates the sex and age-at-death of each individual.

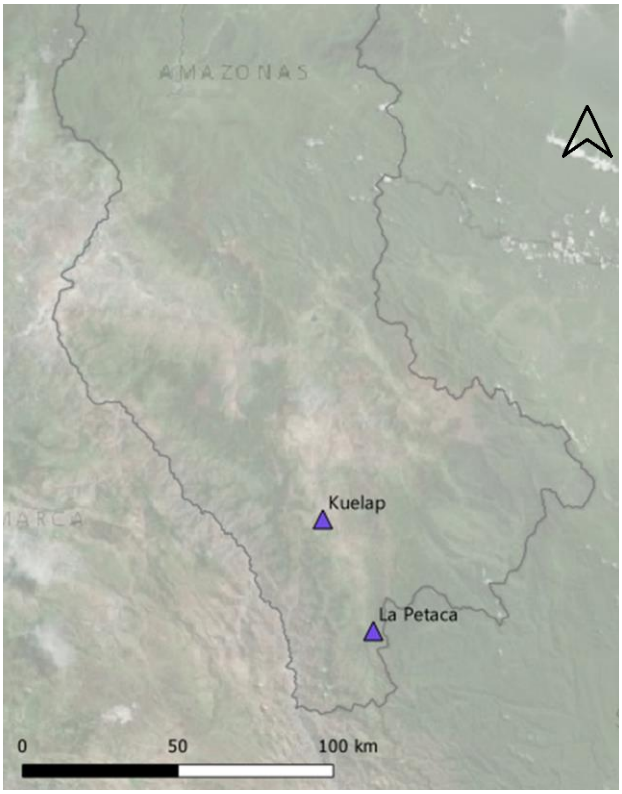

Figure 4: Map of Amazonas, marking where Kuelap and La Petaca are located (Stacey 2019).

2.2.4. Lima Department

Zimmerman's 1981 study focuses on a single example of early colonial trepanation, with a partially preserved mummy from Llactashica (fig. 5), in the Rimac Valley of central coastal Peru (Zimmerman 1981 *et al.*, 497). It is a single individual from the Peabody Museum (#N/8446), and records of its discovery was lost to antiquity. Radiologic examination was conducted on the perforation to determine diagnosis, and the individual's sex and age-at-death was estimated. The article's focus is on the other causes of death for the individual, concluded as neoplastic disease from silver mining and other trauma (Zimmerman *et al.* 1981, 499).

Rogers' 1938 study is based on the osteology collection that was being held at the San Diego Museum in 1938 when the article was written. The collection was found by Dr. Aleš Hrdlička in 1913, and was comprised of 4800 examined crania – 59 of which were trepanned (Rogers 1938, 322). The original location of each of these crania are vaguely described as being from the "western mountains of Peru" (Rogers 1938, 322), though is stated by Rogers to be found in Cinco Cerros (fig. 5). Cinco Cerros is an archaeological site that dates to the pre-colonial era, showcasing a stone fortress and is believed to have been home to a high-altitude settlement of 9,000-13,000 feet (Rogers 1938, 322). It was estimated the crania date to "about the tenth century A.D" and therefore would fall into the period of the Middle Horizon (Rogers 1938, 323). The study identifies the method of trepanation, but does not estimate the sex or age-at-death of the individuals (Rogers 1938, 335).

Figure 5: Map of Lima, marking where Cinco Cerros and Llactashica are located (Stacey 2019).

3. The Nature of the Trepanations

There is a wide degree of variation among trepanations in ancient Peru (González-Darder 2017, 33; Kushner *et al.* 2018, 246; Marino & Gonzales-Portillo 2000, 946). The extent to which elements varied or remained constant will be examined in this chapter. This will be done by looking at the frequencies seen within the data, and comparing the variables through the expression of percentages. Unknown data will be accounted for in these percentages, by the creation of two results – one including the unknown elements and one without. This data will be split by their departments to also show any regional trends that may have been present.

3.1. Method of Trepanning

Trepanation can involve one or multiple holes in the cranial bones, and can be created by a series of different methods. Common methods of trepanation in ancient Peru can be grouped into the following four categories: scraping, circular grooving, boring or drilling and linear cutting (fig. 6). These methods can differ in

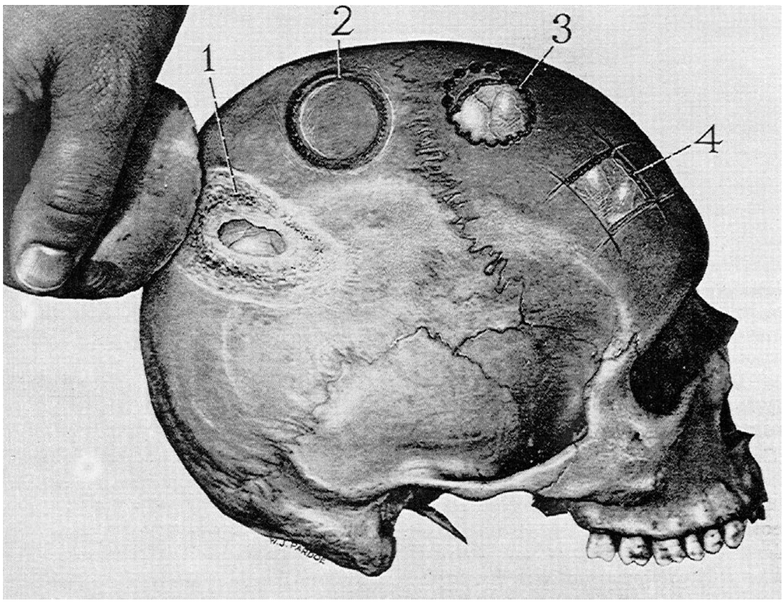

Figure 6: Illustration of the four trepanning methods. 1 = scraping; 2 = circular grooving; 3 = drilling & cutting; 4 = linear cutting (Lisowski 1967 in Verano 2016, 2).

ways that affect the aperture created, the diagnostic features left on the bone and possibly affect the post-operative healing process. There is of course variation within these categories, which can be affected by the location, the tools used or the experience of the surgeon. This variation is significant as it could be a factor that contributes to the healing process and survival rate of the patient.

Scraping involves using a grainy-textured material to abrade the cranial surface in order to gradually remove the bone. The resulting outcome is a rounded hole which is smaller in dimension on the inner table than the outer area of the crania (fig. 7). This method can often get confused with disorganised bone healing due to the rough texture it leaves on the skull. The cutting technique involves a sharp instrument which is hard enough to saw or cut through the cranial table, leaving a polygon-shaped hole (fig. 8). It results in a similar dimension on the inner and outer part of the skull.

Figure 7: A partially healed scraped trepanation on an individual from Apurímac (After Kurin 2008, 490).

Figure 8: Trepanation by linear cutting on an individual from Apurímac (After Kurin 2008, 490).

The drilling, or boring, technique is namely the rotational pressure caused by a hard stone tip that is held either in one hand or with a handle (González-Darder 2017, 33). When healing has not taken place, this method leaves a 'clean cut' finish, unlike methods like scraping or circular grooving, with the possibility of micro-fractures around the area of impact (fig. 9).

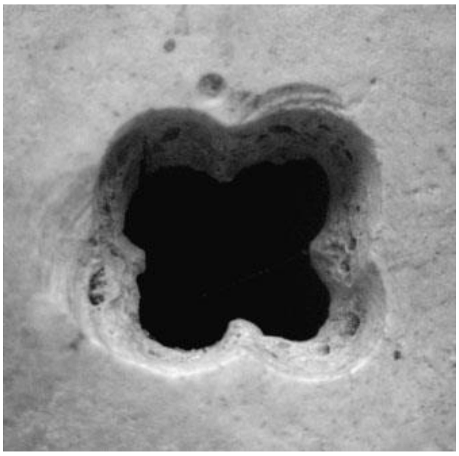

Figure 9: An unhealed drilled trepanation on an individual from Amazonas (Nystrom 2007, 46).

Circular grooving uses carving a depression into the skull with a sharp tipped tool (fig. 10). This depression becomes deeper more gradually than the cutting technique, but are mutually indistinguishable in some cases (González-Darder 2017, 33).

Figure 10: An unhealed trepanation with indicators of circular grooving, on an individual from Cusco (Andrushko & Verano 2008, 8).

Generally speaking, it can be seen in Table 3 that by excluding the unknown elements, the most common technique used among Peru was likely scraping (n=96). This technique is also a form of 'supra-inial' trepanation, which involves the scraping of the periosteum to result in a hole in the skull (González-Darder 2017, 30). It has been found in various other studies to be performed in Peru with an "extremely high incidence" within crania of any age-group or sex (González-Darder 2017, 30).

Table 3: Frequency of the four categories of trepanning methods. Percentages only include the known methods.

	Cusco	**Amazonas**	**Apurímac**	**Lima**	*Total*	*Total known*	% per known method
Scraped	4	0	24	6	34	**34**	35%
Circular grooving	0	5	8	0	13	**13**	14%
Boring/drilling	4	5	12	2	23	**23**	24%
Linear cutting	4	0	1	21	26	**26**	27%
Unknown	97	11	0	31	139	**-**	-
Total	109	21	45	60	**235**	**96**	100%

This frequency of 34 cases, constituting 35% rate of scraping trepanation – along with the knowledge this percentage may be higher but was deemed to be unknown, as well as the corroborated evidence from previous studies – suggest that scraping was the preferred method of trepanation in Peru. The results do not indicate it was done the majority of the time, as linear cutting (26 cases, 27%) and boring/drilling (23 cases, 24%) constitute only slightly less than scraping. The low rate of circular grooving is apparent with only 13 cases being identified (14%). It was said by Kushner *et al.* in 2018 that when methods were compared across Peru, the most common were scraping and circular grooving (n = 649) (Kushner *et al.* 2018, 249). This low occurrence may have been from the smaller sample size, or from the physical similarities between linear cutting and circular grooving – as they can appear indistinguishable at times. However, scraping is unlikely to have been misidentified in this way – making it more likely it has been under-represented rather than over-represented in the results.

Geographical comparisons between the departments are unavailable for the methods used in trepanations. This is due to the small sample size from Cusco, Amazonas and Lima once unknown elements were removed, constituting 59% of the total sample.

3.2. Location of Trepanation

It has been found previously by Kushner *et al.* (2018) that the locations on the crania where trepanations take place vary "by geographical region and time period" – which can be tested using the frequencies found in this sample. In the earlier periods, it was found that trepanations were commonly done on the frontal and occipital bones (Kushner *et al.* 2018, 246), concentrating on the midline of the crania. The positions of the cranial bones, as well as the superior sagittal suture, can be seen in Figure 11. The anterior position indicates the bones on the very front of the cranium, such as the frontal bone and the first half of the parietal bones on each side of the skull. The posterior position indicates the occipital bone, located most posteriorly, in addition to the further half of the parietal bones and a portion of the temporal bones.

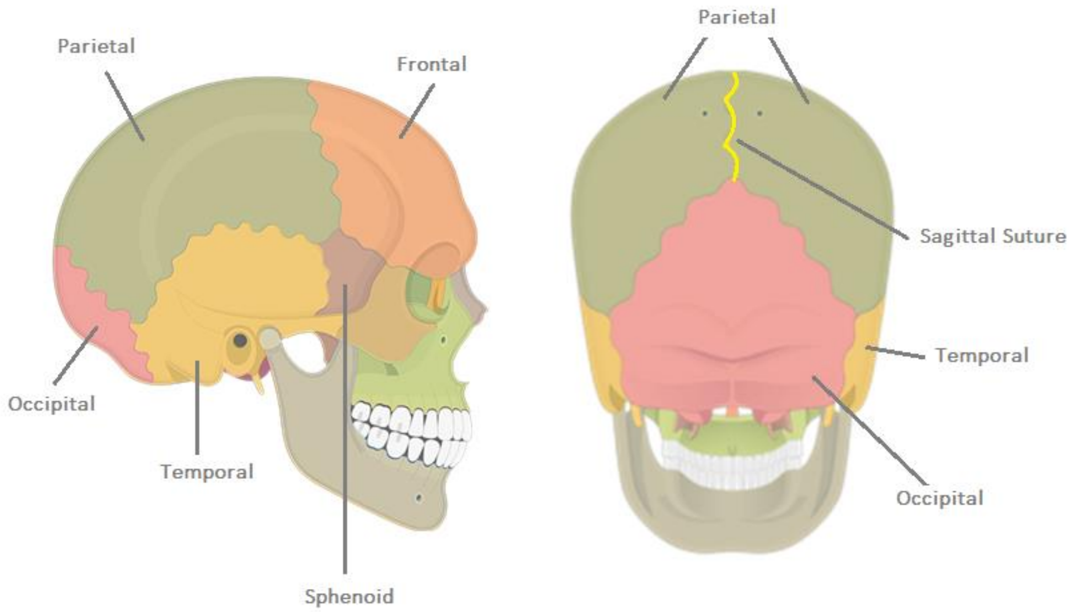

Figure 11: Diagram of the lateral (left) and posterior (right) view of the cranial bones, including the sagittal suture on the superior portion of the skull (Stacey 2019).

What can be found in the data is a clear over-abundance of midline-located trepanations, occurring on the superior part of the crania nearer to the sagittal suture (tab. 4).

Table 4: Location distribution of trepanations on the crania. Percentages only include the known methods.

	Cusco	**Amazonas**	**Apurímac**	**Lima**	*Total*	*Total known*	% per known position
Left - Anterior	12	5	6	0	23	**23**	13%
Right - Anterior	6	0	4	1	11	**11**	6%
Left - Posterior	18	6	17	0	41	**41**	24%
Right - Posterior	7	5	5	0	17	**17**	10%
Midline - Superior	66	5	9	0	80	**80**	47%
unknown	0	0	4	59	63	**-**	-
Total	109	21	45	60	**235**	**172**	100%

The majority of these midline trepanations come from the Cusco department – consisting of 66 cases (n = 109) and constituting 82% of the total midline trepanations found in the sample (n = 80). Possible reasons for the high appearance of midline trepanations may originate from the four sites dating to the Late Intermediate Period (1001-1476 A.D.), in which trepanation was performed prior to major Inca influence. It was found that a variation of location took place during the later time periods away from the nuchal region or temporal fossa to avoid complications relating to bleeding (Kushner *et al.* 2018, 246). It is also seen that there was a deliberate avoidance of the superior sagittal sinus later on (Kushner *et al.* 2018, 247).

However, this may not represent a periodic shift in location preference. By removing the Lima department and the other four unknown cases from Apurímac, a regional overview of locations can be seen (tab. 5). This allows the calculation of the individual percentages of each combination of side and location per department, therefore indicating whether there are geographical trends. As shown in Table 5, Apurímac did not show a preference for midline trepanations, as well as Amazonas. This is interesting as the trepanned crania originated from four Late Intermediate Period sites, similar to Cusco. Interestingly, they do not show such as strong trend towards superior midline trepanations.

Table 5: Location distribution of trepanations from Cusco, Amazonas and Apurímac, including individual percentages of exact position of trepanations.

	Cusco		Amazonas		Apurímac		*Total*	% per position
Left - Anterior	12	11%	5	24%	6	13%	**23**	13%
Right - Anterior	6	6%	0	0%	4	9%	**10**	6%
Left - Posterior	18	17%	6	29%	17	38%	**41**	24%
Right - Posterior	7	6%	5	24%	5	11%	**17**	10%
Midline - Superior	66	61%	5	24%	9	20%	**80**	47%
Total	109		21		41		**171**	100%

Tables 6 and 7 show that the trepanations appeared to be more concentrated on the posterior portion (49%, tab. 6) of the crania, with a preference of the left side in most cases (56%, tab. 7). A preference of the posterior portion and left side was also seen in the Amazonas sites (52% left, 52% posterior), which date to the Late Intermediate Period, but also to the Late Horizon when Inca influence was widespread in central Peru at the time. Perhaps these results are indicative of a geographical difference between Cusco and the lesser centralised departments like Apurímac and Amazonas.

Table 6: Cranial area distribution of trepanations from Cusco, Amazonas and Apurímac.

	Cusco		Amazonas		Apurímac		*Total*	% per position
Anterior	18	17%	5	24%	10	22%	**33**	19%
Posterior	25	23%	11	52%	22	49%	**58**	34%
Superior	66	61%	5	24%	9	20%	**80**	47%
Total	109		21		41		**171**	100%

Table 7: Side distribution of trepanations from Cusco, Amazonas and Apurímac.

	Cusco		Amazonas		Apurímac		*Total*	% per position
Left	30	28%	11	52%	23	56%	**64**	37%
Right	13	12%	5	24%	9	22%	**27**	16%
Midline	66	61%	5	24%	9	22%	**80**	47%
Total	109		21		41		**171**	100%

This does not support the notion that Cusco would have been influenced by the Inca culture faster, as the area geographically acted as their capital of influence – and instead suggests the switch away from midline trepanations happened earlier than expected. In addition to this, by separating the count of trepanations per side (left, right or midline) from the count per location (anterior, posterior or superior), the strong preference for left side trepanations can be seen (37%). While it was not identified to be as common as midline trepanations, it remains to be a significant portion of the sample, especially when considering the weight of bias towards the Cusco sample.

3.3. Biological Profiles

Whilst it is not the aim of this research question to estimate the reasons behind practicing trepanation, it is interesting to see whether there is a certain distribution of the practice among the sample population. In the past, studies that have looked at the biological profiles of those with evidence of trepanations have found it is a fairly equal distribution among the sexes and ages with some exceptions. It was found by Frame (2010) in a sample that extended beyond Peru, that the large majority (53%) of trepanned individuals were male, with a large group of indeterminate individuals (27%) (Frame 2010, 32). This indeterminate group also occurred in this study's sample, and should not be misconstrued as signifying subadults. There are various reasons why an individual's sex is categorised as 'indeterminate', two being the state of preservation of sexually dimorphic bones or a lack of certainty in the prediction. Nevertheless, the higher rates of trepanation among males were also found by Kushner (2018), also finding that it was performed on female crania, and in rare cases on children (Kushner *et al.* 2018, 247). Whether this case is reflected in this study's data will be determined. The age distribution of the practice in the sample data was also looked at, where possible. This consists of four estimated age-group categories and two broader, and potentially overlapping, categories. The subadult group is comprised of those estimated to be under 17 years of age, with young adults being 18-25 years old, middle adults being 26-45 years old and older adults being above 46 years old. An unknown group was created for those individuals that were either not assessed for age-estimation, or for whom age was indeterminate. Alongside this, an adult 'other' group was formed from the age estimations that were found to be inconclusive but could rule out the possibility of the individual being a subadult. It is important to note that the age-at-death estimations do not attempt to date the trepanations in correlation to their age. Therefore in the cases of long-term healing, young adults may have experienced further trepanations but survive to an older age and thus fall into an older age category. The age-at-death estimation of individuals with no healing would indicate the age of trepanation.

Across all four departments a large majority of trepanations were done on male individuals (61%, tab. 8) and less so on the female portion (23%, tab. 8). While the remaining 16% was indeterminate, the majority would continue to be males even in the unlikely case that the 18 indeterminate individuals were from the female portion of the population. This conclusively finds that males were the preferred subjects for trepanation – potentially suggesting there were social influences involved with the practice, such as a gender-related divide.

Table 8: Sex distribution of trepanations. Percentages only include the known sex estimates.

	Cusco	**Amazonas**	**Apurímac**	**Lima**	*Total*	*Total known*	% per known sex
Male	35	12	24	1	**72**	72	61%
Female	19	5	3	0	**27**	27	23%
Indeterminate	12	1	5	0	**18**	18	16%
unknown	0	0	0	59	**59**	-	**-**
Total	66	18	32	60	**176**	117	100%

From the cumulative results of age demographics, shown in Table 9, it can be seen that the most common age of those impacted by the practice were middle adults (44%, tab. 9) who were between the estimated ages of 26 and 45 years of age. There was a fairly moderate distribution of trepanations within younger adults (24%, tab. 9) and older adults (15%, tab. 9), with younger adults appearing to be trepanned slightly more. As it was found by Kushner (Kushner *et al.* 2018, 247), the rate of trepanations on subadults was very low (4%, tab. 9).

Table 9: Age distribution of trepanations. Percentages only include the known age-at-death estimates.

	Cusco	**Amazonas**	**Apurímac**	**Lima**	*Total*	*Total known*	% per known age
Subadult (0-17)	4	1	0	0	**5**	5	4%
Young Adult (18-25)	9	6	13	0	**28**	28	24%
Middle Adult (26-45)	33	7	11	1	**52**	52	44%
Old Adult (46+)	13	1	4	0	**18**	18	15%
Adult other	7	3	4	0	**14**	14	12%
unknown	0	0	0	59	**59**	-	-
Total	66	18	32	60	**176**	117	100%

The results of the biological profiles of the trepanned are inconclusive for the department of Lima due to the constraints of a limited data sample (one case, young adult male). Therefore, a geographically-based analysis only including Cusco, Amazonas and Apurímac sites may be more indicative of the biological profiles of those trepanned in Pre-Columbian Peru. In addition to this, it may be valuable to subcategorise the age groups in order to understand whether there was a preference for trepanning younger or older people in society. This was done by combining the subadult and young adult group to make the 'young' group and combining the middle and older adult group together to make the 'old' group in society. The adult 'other' group was excluded in this analysis.

In doing so, there is the potential to indicate a preference for the older members to be trepanned in the Cusco sites (78%, tab. 10) – or shows many who were trepanned at a younger age continued to show long-term recovery – though as the sample includes both healed and non-healed individuals this indication cannot be confirmed. Both Amazonas and Apurímac show very similar results for the older individuals (53% and 54% respectively, tab. 10). As for the distribution of sex, all three departments disproportionally represented the male population in their samples (tab. 11). Amazonas did not find a significant difference between males and females (Nystrom 2007, 43). The indeterminate percentage, which ranged from 5.6% to 18.2% represented a total of 18% of the sample (tab. 11) and therefore has to be taken into account when looking at the sex distribution, as well as other dispositional factors that could have influenced the total number of males.

Table 10: Young and old age distribution of trepanations from Cusco, Amazonas and Apurímac.

	Cusco		**Amazonas**		**Apurímac**		*Total*	% per category
Young (0-25)	13	22%	7	47%	13	46%	**33**	32%
Old (26-46+)	46	78%	8	53%	15	54%	**69**	68%
Total	59		15		28		**102**	100%

Table 11: Sex distribution of trepanations from Cusco, Amazonas and Apurímac.

	Cusco		**Amazonas**		**Apurímac**		*total*	% per sex
Male	35	53.0%	12	66.7%	24	75%	**71**	72%
Female	19	28.8%	5	27.8%	3	9.4%	**27**	28%
Indeterminate	12	18.2%	1	5.6%	5	15.6%	**18**	18%
Total	66		18		32		**98**	100%

3.4. Number of Trepanations

The number of total trepanations (tab. 12) in the sample is more than the total number of trepanned individuals (tab. 13) because there are instances where 2 or more trepanations take place on the same individual. This can be done in a single instance, or at multiple points in an individual's life – and can show different stages of healing. Data on the number of instances per individual is not available for the Lima sample, as Zimmerman *et al.* features only one individual and Rogers (1938) did not record multiple instances. This may be because only singular trepanations occurred in the sample, but most likely it is because it was deemed not important in the context of the study. Due to this, the results will only include Cusco, Amazonas and Apurímac sites.

Table 12: Trepanned individuals and their distribution across the departments.

	Cusco	Amazonas	Apurímac	Lima	*Total*
Trepanned individuals	66	18	32	60	**176**
% of total trepanned individuals	38%	10%	18%	34%	100%

Table 13: Instances of trepanation recorded and their distribution across the departments.

	Cusco	Amazonas	Apurímac	Lima	*Total*
Total trepanations	109	21	45	60	**235**
% of total trepanations	46%	9%	19%	26%	100%

There are cases where multiple holes created directly next to each other through the method of boring or drilling appear to be the evidence of multiple instances of trepanation. In this study, it should be considered as a singular instance of trepanation. This is because a characteristic of the drilling or boring method includes the creation of multiple holes around a section of the cranium in order to separate it as seen in Figure 12. Multiple trepanations are considered to be as such when they are deliberately made on another part of the cranium, in a manner that is not related to the method used.

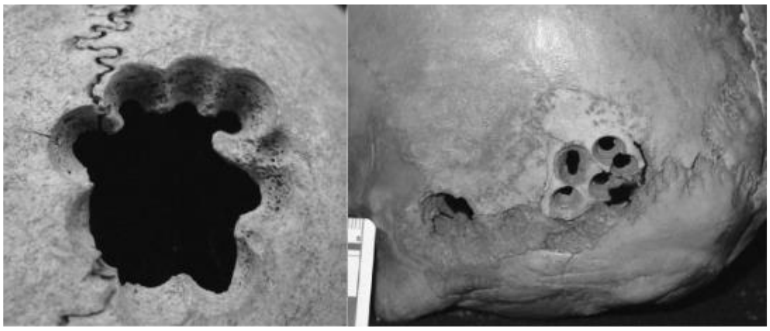

Figure 12: Two examples of singular trepanations from Amazonas, made by multiple drill holes (After Nystrom 2007, 46)

In Figure 13, it is noticeable that three of the trepanations experienced more extended periods of healing compared to the two seen on the top right of the photo.

Figure 13: Example of a Cusco individual with seven separate trepanations, with different stages of healing (After Andrushko & Verano 2008, 7)

In Table 14, the majority of trepanations are a singular occurrence (67%) but demonstrate some differences between reoccurring trepanations between departments. The Cusco sample represents the majority of multiple trepanations, indicating another regional difference between Cusco and the other departments. By dividing the total amount of trepanations per department by the number of trepanned individuals, a comparison can be created between these areas. For every trepanned individual in the Cusco sample, there are on average 1.6 trepanations per person, 1.4 trepanations per person in Apurímac and 1.2 trepanations per person in Amazonas. Overall, there would be an average of 1.5 trepanations per person. There were no instances of above three trepanations occurring in Amazonas, and few (9%, tab. 14) occurring in Apurímac – where as in Cusco this occurred in 17% of the sample.

This is still a minority of cases, but a significantly larger proportion than in Amazonas and Apurímac combined. It is unlikely this difference was due to the evolution of the practice, as the Amazonas, Apurímac and Cusco sites were

Table 14: Frequency of numbered trepanations per individual from Cusco, Amazonas and Apurímac.

	Cusco		**Amazonas**		**Apurímac**		*Total*	% per number
1	40	61%	15	83%	23	72%	**78**	67%
2	15	23%	3	17%	6	19%	**24**	21%
3	8	12%	0	0%	2	6%	**10**	9%
4+	3	5%	0	0%	1	3%	**4**	3%
Total	66		18		32		**116**	100%

largely dated to the Late Intermediate Period – therefore exaggerating the implication that this difference was culturally specific to Cusco.

3.5. Additional Characteristics of Trepanation

In this thesis, quantitative data within the studies were not available on the prevalence of different tools and operative methods. This excludes a large amount of contextual information regarding the tools that might have been used and what was performed prior and post surgery. This is due to restrains in the evidence stemming from the flaws in the archaeological preservation.

The tools and instruments used in Peru for these trepanations are vague and unidentified, apart from the few instances of archaeological evidence found in association with trepanned crania. The material of the tools include obsidian, copper, silver, gold and the region-specific '*champi*', which is known as the Inca Bronze (Marino & Gonzales-Portillo 2000, 946). Other earlier tools included bi-facially flaked obsidian and knives made from chert – in some cases these were found attached to wooden handles (Kushner *et al.* 2018, 246). It cannot be assumed all materials were used for all types of techniques, and it is not known whether a preference existed. An experimental study that used archaeological tools on a cadaver showed that an obsidian silex knife "could not be used in circular movements" and would disintegrate against the crania. Instead, it must have been used as a sawing motion (Marino & Gonzales-Portillo 2000, 949). Separate tools may have been used for opening the scalp, such is the case with the Peruvian *tumi* blade that was not used to open the bone (Marino & Gonzales-Portillo 2000, 946).

Archaeological evidence of pre-operative and post-operative methods are scarcely found because the items were likely single-use, or decomposable along with the soft-tissue. In exceptional cases, mummified individuals who have been trepanned provide us with some insight into the way soft tissue was handled. Certain paraphernalia that may indicate the pre-operative methods of trepanation in pre-Columbian Peru have been discovered– such as bone elevators and dura protectors (Marino & Gonzales-Portillo 2000, 946). The dura protector would indicate they were aware the dura mater needed to be protected, and not broken. There also is speculation, but little evidence, that hallucinogenic drugs were ingested as a form of pain-killer (González-Darder 2017, 34) or fermented corn beverages like *chicha* (Marino & Gonzales-Portillo 2000, 947). Natural remedies to promote blood coagulation may have been used, such as Andean ratania root or the pumachuca shrub (Marino & Gonzales-Portillo 2000, 947).

Some evidence of suturing needles and cotton bandages (Marino & Gonzales-Portillo 2000, 946) that were found have led to theories that post-operative methods included closing the wound in the scalp using a needle and thread (González-Darder 2017, 34; Marino & Gonzales-Portillo 2000, 947). Kurin (2013) analysed a young male who was mummified that exhibited a partly shaven scalp and a "possible poulice" used over the unhealed trepanation (Kurin 2013, 490). Using reports found in historical chronicles, references to Inca knowledge of pharmacology have been made (Marino & Gonzales-Portillo 2000, 942). If antiseptics were used, they would likely have been naturally-derived substances that can be found in the region, whose qualities are known to us now. This includes the 'Peru balsam', which is from a tree called *Myroxylon balsamum* var. pereirae. It is grown in Central and South America, and is known for its antibacterial properties. In addition to this, there were likely other more commonly known substances like tannin, saponins and cinnamic acid (Marino & Gonzales-Portillo 2000, 945).

4. The Survival Rate of the Trepanations

Previous studies that have looked at the survival of trepanations in Peru, namely Kushner *et al.* in 2018, found that survival rates for ancient Peruvian trepanations exceeded those which were recorded in the American Civil War from the 19th century (Kushner *et al.* 2018, 251) and were regionally different (Kushner *et al.* 2018, 249). As it was explored in the previous chapter about the characteristics of trepanation, there were observable differences in the practices between sites located in different departments. Therefore, due to the survival rates that were found in studies before this thesis, it can be hypothesised that these regional variables will also be reflected in the survival rates between sites in different departments of Peru.

The basic biology of the anatomy commonly affected by trepanations will be explained in this chapter, before defining the survival criteria which dictates our perspective of who did and did not survive trepanation in Pre-Columbian Peru. In regards to our knowledge of cranial healing after trauma, the intra-operative risks that occur during surgery will be addressed, specifically blood-loss, as well as post-operative complications, namely the risk of infection and the piercing of the dura mater.

4.1. Biology of Trepanation

Knowing the basic biology of the cranial vault is relevant to the understanding of how trepanations are made and their subsequent recovery. Firstly, the location of blood vessels were likely to have played a part in the survival rate of a patient, as puncturing an artery increases the risk of fatal blood-loss occurring intra-operatively. Secondly, the soft tissue affected by the trepanation process is often overlooked as a source of evidence of survival as it is not preserved in many cases. This does not make it less relevant to the healing processes at hand, and the potential risks of fatal infections occurring post-operatively.

The cranium vault consists of the paired parietal, frontal bones, the occipital bone and the squamous portion of the temporal bones. The majority of the vault bones are covered by the scalp (fig. 14). The scalp consists of skin which hair follicles sit within, a subcutaneous fat layer of connective tissue that contains a network of blood vessels, the fibrous (*epicranial*) aponeurosis, loose connective tissue and a thin periosteum called the *pericranium* (Toyne 2015, 30). Beneath the scalp are the vault bones, comprised of two layers of cortical, dense bone which are separated by a layer of spongy, cancellous bone. The layers which separate the vault bones and the brain consist of two layers of dura mater (*endosteal* and *meningeal*), the arachnoid layer and the subarachnoid space.

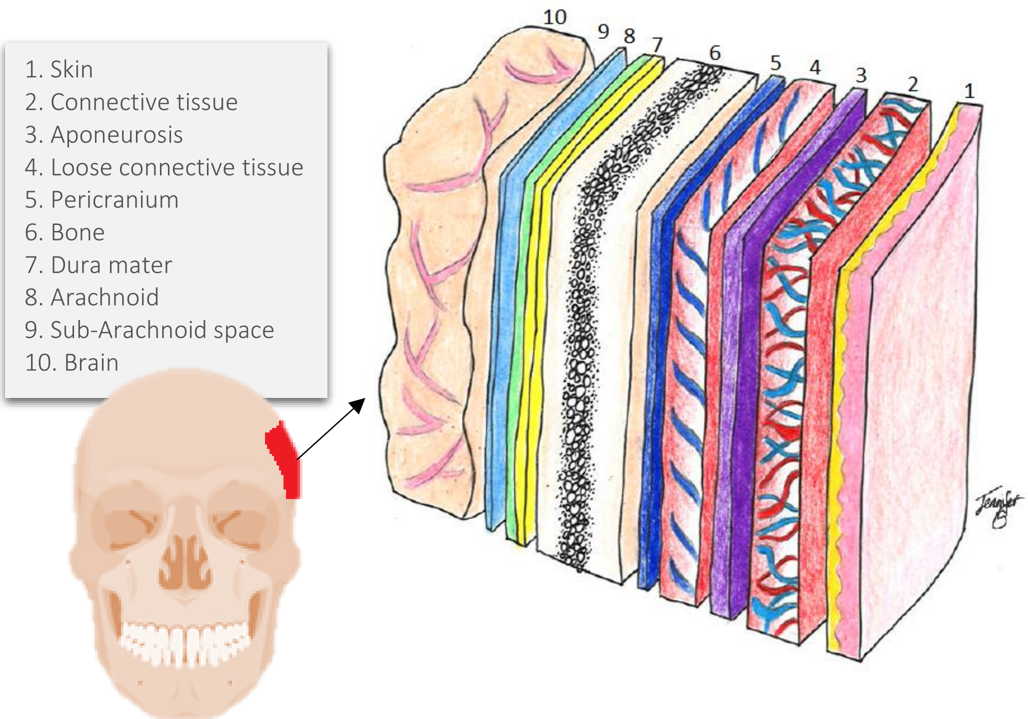

Figure 14: An illustration of the layers that make up the area of the head (cranial vault bones) that is commonly associated with trepanation (Stacey 2019).

These layers act as protection to the brain which is directly underneath. Muscle attachments are located on certain areas of the frontal, parietal and occipital bones. Surival within this study is assessed on new bone formation, though it is acknowledged that the healing of various layers of soft tissue would give a better indication of the level and rate of healing of the trepanned individual.

4.2. Survival Criteria

The main element of identifying survival in the study of trepanations is formally a bone response or regeneration, as this is what is preserved archaeologically. The healing processes of cranial bones are extensive and therefore makes this marker a fairly reliable one for this purpose. The stages of survival as defined in this study range from 0–2, and include no biological responses to long-term regeneration of the cranial bone. The complications that can detrimentally impact the healing process are addressed in relation to these stages. For the purpose of defining survival for this thesis, only Stage 2 is considered survival.

4.2.1. Stage 0

It is assumed that an initial step of ancient Peruvian trepanation is often the removal of the hair and the folding back of the scalp (Kurin 2013, 488) in order to keep the area of trepanation clear. After this, a method of trepanation is used with a tool similar to those discussed in the previous chapter. Immediately after the procedure, inflammation around the trauma occurs on the soft tissue.

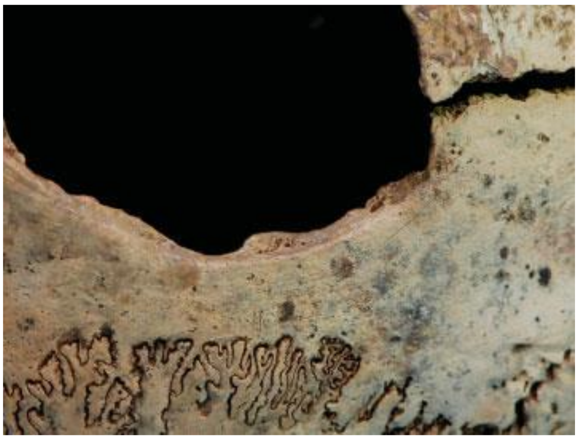

Figure 15: A stage 0 trepanation from Cusco showing no biological reaction, clear margins and small mechanical traces created during the procedure (Andrushko & Verano 2008, 8).

Typically, if physical or mechanical marks remain on the cranium after death – such as micro-fractures which occur with the drilling method, or residual cutting marks from the linear cutting method – it is assumed that death occurred early on in the process of trepanning (González-Darder 2017, 31). Clean boarders of the trepanation with "no signs of scarring" can also indicate this phase (González-Darder 2017, 32). This can occur within surgery, in the first days of recovery or if the trepanation was performed on a post-mortem individual. This stage is defined as '0', indicating no evidence of bone reaction (fig. 15).

4.2.2. Stage 1

Around one to four weeks of survival after the surgery, with continuous healing, a "superficial osteoporosis" (fig. 16) appears around the point of trauma which is caused by the damage or removal of the periosteum (González-Darder 2017, 31). It was found by Barbian & Sledzik (2008) in a modern study of cranial healing that the earliest case of osseous activity on the cranium appeared 5 days post-facture – and by the fourth week at least one osseous response was found in all subjects (n=127) (Barbian & Sledzik 2008, 265).This rudimentary osteoclastic activity marks the initial transition from short-term healing into long-term healing. Albeit, it is at this point in the recovery process that post-operative complications can often occur (see chapter 4.4) and prolong the healing process or even kill the individual. Those identified with early periosteal or osteoclastic reactions, or with signs of bone infection are placed within Stage '1'.

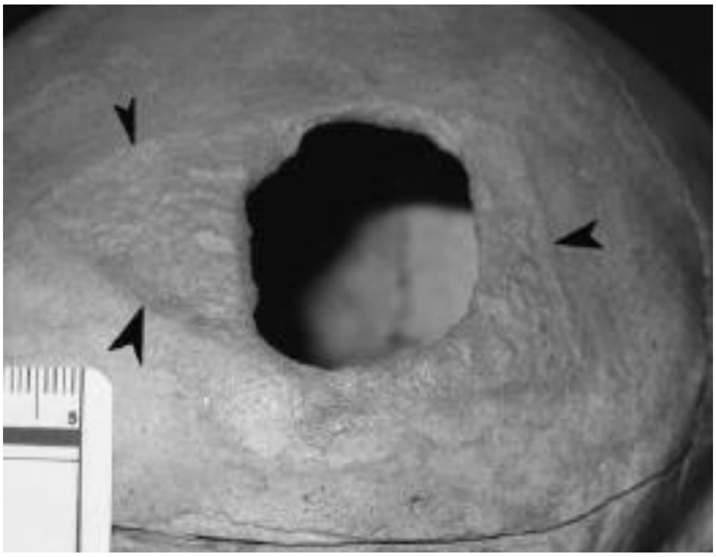

Figure 16: A stage 1 trepanation from Amazonas showing a periosteal reaction in a triangular area around the trepanation (After Nystrom 2007, 45).

4.2.3. Stage 2

The events of Stage 2 occur over a longer period than the first two stages, ranging from months to multiple years of healing. The necrotic superficial bone that appeared in Stage 1 begins to gradually disappear due to "physiological resorption processes" (González-Darder 2017, 31) also known as osteolysis. The risk of infection is prevalent but generally decreases as the scalp continues to heal. The initial 'clean-cut' boarders of the trepanation is made to be irregular and blurred (fig. 17) due to the exposure of cancellous bone. Bone remodelling first takes place on the inner table, forming a 'thin shelf next to the dura mater' (Rogers 1938, 333).

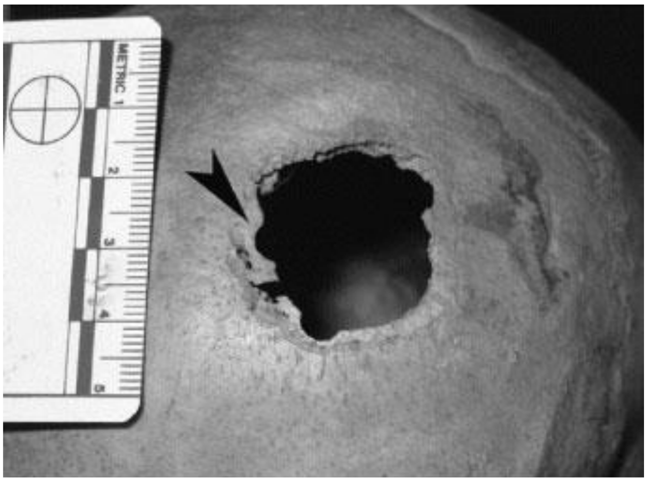

Figure 17: An early stage 2 trepanation from Amazonas showing the irregular bone remodelling around the point of impact (After Nystrom 2007, 44).

During the final phases of osteolysis, after approximately eight weeks (González-Darder 2017, 31), the marks of long-term recovery is evident on the cranium. The body's bone metabolism regularises the edges of the trepanation and 'smooths' the area around the initial trauma In accordance with Wolff's Law, the lack of 'osteogenic stimuli' prevents the remodelling of the bone to completely cover the aperture (González-Darder 2017, 31) and thus can only heal over to a certain extent. The aperture decreases in size, on both the inner and outer table, eventually thickening the scar matrix that can be seen around Figure 18.

Figure 18: A later stage 2 trepanation from Cusco showing the smoothed, regular area around the point of impact with a scar matrix (Andrushko & Verano 2008, 7).

4.3. Intra-operative Complications

Intra-operative complications in trepanation most likely comprised of excessive, uncontrolled blood-loss. It is known in modern neurosurgery that excessive blood-loss occurs either from the layer of cancellous bone in the cranium (fig. 14) or the middle meningeal artery which supplies the blood to the cancellous part of the bone (Weber & Wahl 2006, 537). Trepanations which rupture the meningeal artery puts the individual at a high risk of death due to blood-loss and would not allow time for the body to show signs of healing before succumbing to the damage. A trepanation in which this occurs would likely be categorised as a 'Stage 0', meaning no signs of healing or biological reaction were found. A common practice during modern neurosurgery is the clipping and cauterisation of the superficial temporal artery located on the scalp in order to manage the risk of blood-loss – a similar practice may have been known in ancient Peru.

Another intra-operative complication that can occur is the piercing of the dura mater, in which the level of risk is dependent on location. The consequences to this is not as well understood as excessive blood-loss. It has been speculated within modern medicine that the breaking of the dura mater initially can 'disturb the equilibrium' and thus increases the risk of a cerebral edema (Jha *et al.* 2019, 230). A cerebral edema is related to this equilibrium found between brain tissue water, blood and the brain – and is caused when the pressure within the dura mater is released (Jha *et al.* 2019, 231). This can be in the form of an epidural hematoma which produced dangerous 'inflammatory responses' and an accumulation of blood within the skull.

4.4. Post-operative Complications

The presence of infection in the cranial bones around the trepanation – in itself – is a sign of post-trepanation survival as it indicates a strong biological reaction (González-Darder 2017, 32). By this definition, a high percentage of survival can be achieved only by the first signs of healing (Stage 1), but extensive survival (Stage 2) requires overcoming the post-operative complications that can occur during this healing process – namely, infection. Extraneous risk factors such as hair or bone flaps have been studied in the past for their contribution to the risk of infection post-operatively. It was found by Winston (1992) that hair was shown to not increase bacterial contamination of neurosurgical wounds – and that the removal of hair prior to trepanation was unlikely to impact this risk (Winston 1992, 320). Weber & Will (2000) found that the size of bone flaps did have an impact on the risk of infection – with those greater than 70mm in diameter increasing the likely hood of contracting osteomyelitis (Weber & Will 2000, 46). Other risk factors may have included prior infection before the trepanation and 'poor soft-tissue coverage' (Baumeister *et al.* 2008, 195).

Signs of infections which can be seen archaeologically include periostitis and osteomyelitis. Periostitis is a prolonged inflammation of the periosteum, limited to the outer layer of the bone (Tótora Da-Gloria *et al.* 2011, 137), and can lead to a 'periosteal bone deposition' over the cortex (Lovell 1997, 146). Osteomyelitis is found to be located inside the bone, forming cloacal openings that enter the medullar cavity (Tótora Da-Gloria *et al.* 2011, 138). Skull-based osteomyelitis is more difficultly managed compared to its manifestation post-cranially – but is reactive to antibiotic treatments (Pincus *et al.* 2009, 73).

In the event of an infection, a long-term recovery may still have been possible in Pre-Columbian Peru. The discovery of needles and thread in association with trepanation sites suggest the wound was kept closed. According to Toyne (2015), the application of topical medicinal herbs would prevent 'common streptococcal' bacteria that could lead to necrosis of the outer table of the cranium and ultimately prove fatal (Toyne 2015, 39). However, it is believed that these infections can remain non-lethal by keeping the dura mater layer intact during the trepanation (Weber & Wahl 2006, 542) – which may have been easier by using a more controlled method of scraping rather than the drilling or cutting methods.

4.5. Survival Rate

The survival rate in the entire sample, where it was applicable, totalled to 54% (tab. 15) – meaning that 54% of the trepanations in this study achieved long-term healing. Of all known cases, 72% of trepanations experienced healing to some extent – whether limited or extensive. This result may indicate a majority of the individuals who trepanned had at least minor knowledge of areas that were safe to impact as well as how to avoid excessive blood-loss during the trepanation.

Table 15: Frequency of total survival stages among all studies and departments.

Healing Stage	**Cusco**	**Amazonas**	**Apurímac**	**Lima**	*Total*	*Total known*	% per known stage
0	4	6	16	13	**39**	39	29%
1	4	4	6	10	**24**	24	18%
2	4	9	23	37	**73**	73	54%
unknown	97	2	0	0	**99**	-	-
Total	109	21	45	60	**235**	136	100%

In comparison with other similar studies, this percentage is slightly lower than is usually reported. Kushner *et al.* (2018) found that survival rates in Peru ranged from nearly 40% in the earlier time periods (400-200 B.C., n = 59) to as high as

53%-91% later on (1000-1400 A.D., n = 430) (Kushner *et al.* 2018, 249). The majority of the sample used in the survival rate were dated to the Middle Horizon and the Late Intermediate Period which would place it slightly later than Kushner *et al.*'s early sample. Therefore, this could mark the transitional point between the lower survival rates into the higher percentages seen slightly later on in Pre-Columbian Peru.

Lima displayed the highest rate of long-term healing among all departments (tab. 16), followed by Apurímac, Amazonas and Cusco. Although, when comparing the four areas, it is noticeable that those with a larger sample size (Apurímac and Lima) have a larger concentration of Stage 2 trepanations (51% and 62%, respectively). This may be because the intricacies of healing may be easier to identify when supplied with a larger collection to act as a comparison. The Cusco sample did not record instances of healing of the trepanations and therefore a small minority (11%, n = 109) of trepanations could be analysed through photographic evidence within the study by Andrushko & Verano (2008).

Table 16: Frequency of known survival stages, with percentages per department.

	Cusco		**Amazonas**		**Apurímac**		**Lima**		*Total*	% per known stage
0	4	33%	6	32%	16	36%	13	22%	**39**	29%
1	4	33%	4	21%	6	13%	10	17%	**24**	18%
2	4	33%	9	47%	23	51%	37	62%	**73**	54%
Total	12		19		45		60		**136**	100%

4.6. Methodological Influences of the Survival Rate

Cross-tabular analysis between the stages of survival and the methodologies used within the procedure can connect the nature of trepanation, investigated in the first part of this research, to the survival rate. This can assess whether the survival rate was influenced by the trepanning technique used or location on which the trepanation was performed. This analysis is based on the assumption that the trepanning characteristics of location and technique have the potential to impact the longevity of the patient's life.

4.6.1. Technique of Trepanation vs. Survival

The cross-tabular analysis of the technique of trepanation against the rate of survival stages was only available for the departments of Apurímac and Amazonas, from Kurin's (2013) and Nystrom's (2007) studies. By displaying the frequencies in this way, it allows us to see if some methods produced a higher survival rate within the sample. It can be seen below that among the sample, long-term healed trepanations performed by scraping was the most frequent outcome (38%, tab. 17) within the Apurímac and Amazonas data, followed by unhealed drilling trepanations (27%, tab. 17). Seven cases of circular grooving also continued to heal extensively (13%, tab. 17).

Table 17: Method vs. survival stage from studies in Apurímac (Kurin 2013) and Amazonas (Nystrom 2007) n = 56.

		Method								
		Scraping		Drilling/Boring		Circular Grooving		Linear Cutting		**Total**
Survival Stage	0	-	-	15	27%	4	7%	2	4%	21
	1	3	5%	1	2%	2	4%	1	2%	7
	2	21	38%	-	-	7	13%	-	-	28
	Total	24		16		13		3		

Remarkably, neither the drilling/boring method nor the linear cutting method showed signs of long-term survival. The data used in this analysis potentially argues that slower, more controlled methods may have been more effective at ensuring long-term survival. This may be due to the measured nature of scraping and circular grooving techniques, and their limited risk of piercing the dura mater, which when intact, lessens the risk of serious infections. However, the sample size (n = 56) only included data from two departments, which may not provide a result that can be applied among multiple regions of Pre-Colonial Peru.

Further research within the departments of Lima and Cusco is advisable in order to support the link between controlled methods and survival of trepanations.

4.6.2. Location of Trepanation vs. Survival

Cross-tabular research on the relationship between the location of trepanation and the rate of survival stages was available only in the department of Amazonas, with the use of Nystrom's (2007) and Tonye's (2015) data. It can be assumed that the location of trepanation can influence the survival rate because there are areas on the cranium which harbour major blood vessels. The most relevant of these are the middle meningeal arteries, located across the frontal, temporal, parietal and sphenoid skull bones (fig. 19). Therefore, trepanning in many locations on lateral portion of the cranium poses a risk of excessive and fatal blood-loss. This risk is magnified when trepanations are done within the pterion region, which is located where four bones join. This arrangement creates a weak-point in the skull, in addition to covering part of the middle meningeal artery.

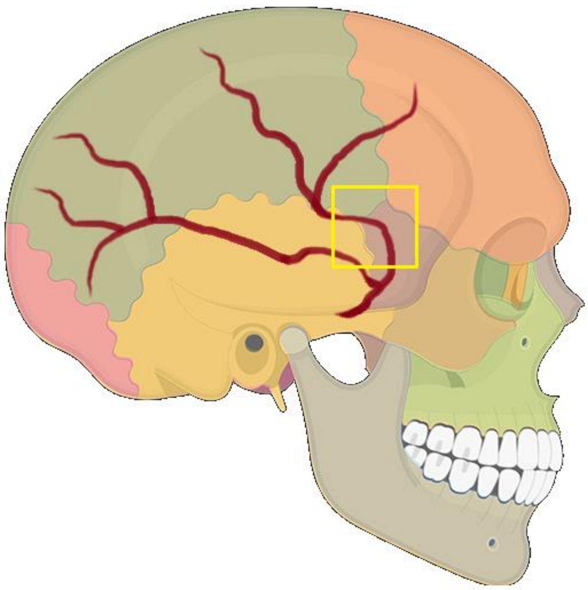

Figure 19: Lateral view of the skull, showing the middle meningeal arteries (red) and the pterion region (yellow) (Stacey 2019).

The results of the comparison of location and survival rates take into account two elements of location – the cranial area and the cranial side. The area is based on the general area of the trepanation in relation to the frontal area (anterior view), the back areas of the skull (posterior view) and the top view of the skull (superior view). The side is based on the lateral areas that the trepanation is located on, either on the left or right. Trepanations reported to have occurred around the pterion region is likely classified in the data as being on the anterior area of the left or right part of the skull. With this in mind, it can be seen in Table 18 that within the department of Amazonas, the two most frequent outcomes included trepanations resulting in Stage 0 survival on the left posterior portion, and Stage 2 survival on the left anterior portion. Both of these occurred the same amount of times (21.1%, tab. 18). Both also represented the most common locations for Stage 0 and Stage 2 survival, while Stage 1 survival did not show a preferred location. It is difficult to find a pattern within this data, as the small sample is spread across many groups within the table. As well as this, it is unlikely that trepanations occurring on the left anterior portion of the skull has a 100% Stage 2 survival rate, as it indicates in the data. This is because the anterior portion is covered partly by the middle meningeal artery. Therefore, the connection found between the location of trepanations and the survival rate remains inconclusive. More data from Apurímac, Lima and Cusco are needed – with a focus on a larger sample size.

Table 18: Location of trepanations vs. survival stage from studies in Amazonas (Nystrom 2007, Tonye 2015) n = 19.

		Cranial Side										
		Left - Anterior		Right - Anterior		Midline - Superior		Left - Posterior		Right - Posterior		**Total**
Survival Stage	0	-	-	-	-	1	5.3%	4	21.1%	1	5.3%	6
	1	-	-	-	-	2	10.5%	-	-	2	10.5%	4
	2	4	21.1%	-	-	2	10.5%	1	5.3%	2	10.5%	9
	Total	4		0		5		5		5		

5. Discussion

5.1. Confounding Factors

Confounding, or influencing, factors are important to identify for many types of studies. They are especially important when a researcher's aim is to define the characteristics of a practice in order to generalise it within a larger region – which concerns this thesis. In the case of trepanation studies, there are a variety of confounding factors that have the ability to influence the characteristics and survival rates of trepanations, and therefore are relevant to the discussion of these results. Such factors include instances of pseudo trepanation and the issues with the survival criteria and the sample used.

5.1.1. Pseudo Trepanation

Verano (2016) investigated cases of 'pseudo trepanation' in comparison to alternative diagnoses, finding that some previously identified cases of trepanation, in actuality, have very differing origins (Verano 2016, 2). The identification of trepanation can be unsuspectingly misleading at times. While the appearance of trepanation on the cranium is often striking, there are various causes for holes made in the cranium – purposeful or otherwise. For the purposes of this study, all crania within the sample studies determined to have cases of trepanation were accepted as such. With the aid of photographic evidence for some of the cases, it is highly likely they were dealing with real cases of trepanation – but it does not entirely remove the risk of pseudo trepanation impacting the results. In order to avoid instances of pseudo trepanation in further research on this topic, the researcher should be aware of other diagnoses.

Firstly, the existence of pre-mortem cranial trauma or injury can create similar markings to trepanation. This could include the damage made by cranial tumours, bone infections, metabolic lesions, 'biparietal thinning' (fig. 20) (Verano 2016, 4) or trauma fractures caused by violence (González-Darder 2017, 30).

Secondly, natural taphonomic agents that can cause post-depositional pseudo trepanations include chemical or mechanical processes that erode, corrode or abrade the cranium and animal gnawing by rodents (fig. 21). Other post-depositional effects also include those during excavation, such as crushing of the cranium, material loss or damage during cleaning processes (González-Darder 2017, 30).

Figure 20: Cranium of an older adult who experienced biparietal thinning who experienced associated breakage (After Verano 2016, 4).

Figure 21: A cranium previously declared as 'trepanned' but is argued to be caused by a combination of post-mortem breakage and rodent gnawing (After Verano 2016, 7).

5.1.2. Issues with the Sample

As the secondary data for this thesis originated from different articles, written in different years, there are expected discrepancies between the data. For example, Rogers (1938) did not provide any age-at-death or sex estimations because the methods used for this currently were not available at the time. Yet, even in the most recent articles there were disparities in the data. Because of this, sample sizes for each characteristic slightly changes and impacts the range of the sample. To account for this, percentages seek to remove the discrpancies between department samples, sometimes opting to exclude a department from the analysis so as not to create misleading results with a high 'unknown' margin.

5.1.3. Issues with the Survival Criteria

There are some difficulties when applying the survival criteria to this thesis' secondary data that are important to identify. In the absence of photographic evidence of the aperture, the specific criteria cannot be personally applied by the researcher. However, as the survival criteria within this study was formed on the basis of criteria defined within the articles of the sample data, the articles score survival on a very similar basis and thus mostly removes this issue. The technique used to trepan can also affect the appearance of the aperture, for example scraping can mimic certain bony regrowth that happens post-operatively, but it is assumed that as this issue was addressed within the articles, this was considered during the scoring of survival.

A second issue that can occur when applying the survival criteria is an issue for all studies in this field, and therefore presents ways to work around this. The issue being that the lack of biological reactions which categorise the '0' healing stage can indicate either death very shortly after the procedure as well as the use of post-mortem crania to practice techniques of trepanning. It was said by Chenge *et al.* (1996) that there may have been 'young Peruvian surgeons' that practiced trepanation on the dead to 'improve their skill or as part of an autopsy' (Chenge *et al.* 1996, 256). This poses a direct issue to the survival rate, as a high occurrence of Stage 0 healing could indicate either that there was a deliberate effort to practice and improve the techniques used in the surgery – acting as a direct testament to ancient Peruvian medical improvement, or that many people died before experiencing healing. It has also been thought that a high rate of mortality could have been a result of the original injury that may have led to the individual being trepanned (Chenge *et al.* 1996, 258).

5.2. Age-at-death vs. Survival

As we can only observe the estimated age-at-death of the individual, there is some difficulty when investigating what the proportion of age groups were within the trepanned individuals. Those who were trepanned and achieved Stage 2 survival may have developed from a young adult into an older adult before death, thus appearing in the statistics as an older adult who was trepanned. This is misleading, as the aim was to define which age groups in Pre-Colonial Peru were trepanned most often. Instead, the statistics represent the ages at death, whether it was related to the individual's trepanations or to another cause. In order to address this, this sub-chapter will use the age-at-death statistics from Kurin (2013), Nystrom (2007) and Tonye (2015) to compare the age groups of individuals against their stage of survival. As this analysis was applicable with three studies, the data can only represent those with known age-at-death in Amazonas and Apurímac, and do not include the other departments.

The comparisons will be conducted in two parts – the first part including individuals with instances of Stage 0 and 1 healing. As Stage 0 represents almost immediate death, and Stage 1 represents survival of around a month, it is highly likely individuals who meet this type of survival criteria did not change age-groups before their death. Therefore, this comparison may present a more accurate distribution of the age-groups that were most often trepanned. The second part includes the age-at-death of individuals with long-term, Stage 2 healing. While the age-at-trepanation cannot be extrapolated from the Stage 2 sample, it can show to what extent the results may have been affected when extensive healing takes place on trepanned individuals.

5.2.1. Age-at-death of Stage 0 and 1

There was a total number of 23 individuals in which this analysis could be applied to, not including those with indeterminate healing or age. It can be seen in Table 19 that the most common age-at-death for individuals with Stage 0 or Stage 1 survival was within the young adults category (18-25 years old), suggesting that it was most commonly young adults that were trepanned in the Amazonas and Apurímac sample (total 43.5%, tab. 19). The second most common age-group was the adult 'other' category (30.4%, tab. 19), consisting of known adults without a known specific age range. This category was included because it informs that such individuals were not trepanned subadults, however they may have been between 18-46 years old, leaving a large gap for consideration. A smaller proportion of this sample were middle adults (17.4%, tab. 19), and even less were old adults (8.7%, tab. 19) which suggests older members of society were less frequently trepanned in comparison to the younger adults. This could indicate influences of status in society that is dictated by the age of the individual, or potential correlations with those in society that partake in violence who were likely within the young and middle adult age groups. These speculations cannot be confirmed, as there is a lack of data for those in Cusco and Lima as well as a large group of adults without a specific age range.

Table 19: Age-at-death vs. Stage 0 and Stage 1 survival from studies in Amazonas (Nystrom 2007, Tonye 2015) and Apurímac (Kurin 2013) n = 23.

		Age Group										
		Subadult (0-17)		Young Adult (18-25)		Middle Adult (26-45)		Old Adult (46+)		Adult other (unknown range)		*Total*
Survival Stage	0	-	-	9	39.1%	1	4.3%	-	-	5	21.7%	15
	1	-	-	1	4.3%	3	13.0%	2	8.7%	2	8.7%	8
	Total	0	(0.0%)	10	(43.5%)	4	(17.4%)	2	(8.7%)	7	(30.4%)	

5.2.2. Age-at-death of Stage 2

Within the Stage 2 sample group, there was a total number of 27 individuals in which this analysis could be applied to, not including those with indeterminate healing or age. Remarkably, this sample group was larger than that of Stage 0 and Stage 1 combined (tab. 19) showing the ratio of short to long-term survival. It was initially hypothesised that the majority of the Stage 2 sample would range between the middle to older adult age groups. This hypothesis was based on the total sample of trepanated individuals, with the subadult and young adult groups constituting less than half (28%, tab. 9) of the known age sample. In addition to this, it is likely that individuals who were trepanned and survived months or years after the procedure were in a generally better condition of health than others and therefore lived into the later age groups.

After collating the data and creating Table 20, it was seen that this hypothesis was proven to a certain extent, but for perhaps more reasons that the ones theorised. Table 20 shows that over half (51.9%) of the long-term survivors of trepanations within the sample were middle adults (26-45 years old), and when combined with the older adult category, constitutes 63% of the sample.

Table 20: Age-at-death vs. Stage 2 survival from studies in Amazonas (Nystrom 2007, Tonye 2015) and Apurímac (Kurin 2013) n = 27.

	Age Group										
	Subadult (0-17)		Young Adult (18-25)		Middle Adult (26-45)		Old Adult (46+)		Adult other (unknown range)		*Total*
Survival Stage 2	1	3.7%	9	33.3%	14	51.9%	3	11.1%	-	-	27

This is a significant change from the combined percentage of the middle adult and old adult age groups in Stage 0 and 1 (26.1%, tab. 19) therefore indicating a cause behind the shift in middle to older adults when healing takes place. Table 19 displays a clear overabundance of trepanned young adults (43.5%), which, if they had experienced long-term recovery, may have developed into the middle to older adult category before death. This can explain why a larger amount of older individuals are placed in Stage 2, suggesting many of them were trepanned as a young adult. The figure for trepanned young adults is potentially higher than what can be demonstrated in the statistics, but with this comparison it strengthens the argument that trepanations in Amazonas and Apurímac were most commonly done on young adults.

5.3. Comparisons with other Trepanation Studies

In order to contextualise the results on the nature and survival of trepanations in Peru, comparisons will be made from similar research that has been conducted in other places in the world. This comparison will include data from Britain, Southern Russia, Italy, Anatolia and North America (fig. 22). Where applicable, the technique and location of the trepanations, the age-at-death and sex of the individuals, as well as the rate of survival, will be discussed in regards to the results found in this thesis.

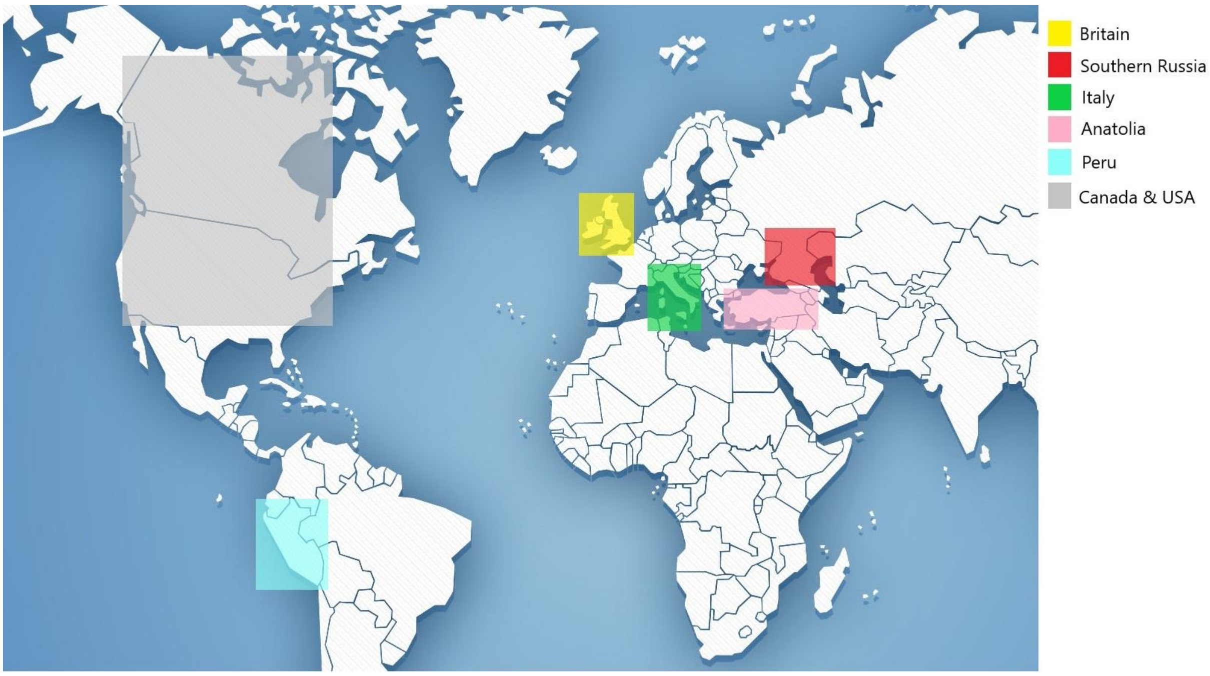

Figure 22: World map showing the locations of the trepanation studies that are included in the comparison.

The British data is from a chapter written by Roberts & McKinley (2008), which documented 62 individuals with trepanations, dating from the Neolithic (4,000-2,000 B.C.) to the Post-Medieval period (16th century) (Roberts & McKinley 2008, 55). The data from Southern Russia was examined by Gresky *et al*. (2016) and includes 13 trepanned individuals who date from the Eneolithic (5th millenium B.C.) to the middle Bronze Age (3rd millennium B.C.) (Gresky *et al*. 2016, 666). Giuffra & Fornaciari (2017) documented a collective study of 54 individuals with trepanations from Italy, dating from the Neolithic (5th millennium B.C.) to the 'modern age' (Giuffra & Fornaciari 2017, 746). Data from Anatolia (modern day Turkey) was published by Erdal & Erdal (2011) on 40 trepanned individuals who are dated from the Aceramic Neolithic (10,000 B.P.) to the Late Ottoman period (17th century) (Erdal & Erdal 2011, 506). Stone & Miles (1999) collated data on 19 trepanned individuals from pre-Columbian and post-Columbian North America - eight of whom were found in the United States of America and eleven being found within Canada (Stone & Miles 1999, 1015).

5.3.1. Methods of Trepanning

The methods used to trepan individuals were subject to slight geographical variation, but consisted mostly of similar techniques across the world. These techniques include scraping, drilling and cutting – all of which are found in Peru. The North American study did not record the frequency of each method, and therefore will not be included in the comparisons of methods.

Differences that were noted was an absence of the circular grooving method within most regions, except for Peru (14%) and Southern Russia (46.2%). It is possible that variations of circular grooved trepanations may have been identified by researchers as cutting, though this is unlikely to have caused such an absence. In addition to this, trepanations from the British sample included a method of 'gouging', constituting 10.6% of the sample (Roberts & McKinley 2008, 63). This method was not recorded in Peru, or in any other region, suggesting that certain methods of trepanning can remain specific to a region or time period, while sharing similarities with other methods. Other differences within the frequency of methods can be explained by the variation of the researcher and their criteria. Mixed methods were recorded in Southern Russia, at 23% (Gresky *et al*. 2016, 669), and in Italy, at 24.1% (Giuffra & Fornaciari 2017, 760), while the Peruvian studies often did not mention the possibility that a combination of techniques could be used. Therefore, it cannot be assumed that mixed trepanning methods did not occur within Peru. Perhaps the discovery of this phenomenon elsewhere suggests this possibility should be looked at in future research.

The most common method used to trepan in Peru was the scraping method at a rate of 35% (tab. 3). This is also seen in Italy, with 40.7% (Giuffra & Fornaciari 2017, 758) and Britain with 57.4% (Roberts & McKinley 2008, 63). Scraping was observed in 12.5% of the Anatolian sample (Erdal & Erdal 2011, 513), but was said to have a statistically significant association with the "highest number of long-term healing" trepanations (Erdal & Erdal 2011, 527). Instead, Anatolia showed the highest frequency of drilled/bored trepanations per region, at 45% (Erdal & Erdal 2011, 511; 518). The Southern Russian sample found the method of grooving to be the most frequent, at 46.2%, but included increments of scraping at least 69% of the time (Gresky *et al*. 2016, 669). It is remarkable that a preference towards the method of scraping can be seen within four distant regions, and parallels its association with healing as it is found in Peru (tab. 17).

5.3.2. Location of Trepanation

The descriptions of where trepanations were located on the individuals from each region were, expectantly, reported in different manners. This made comparisons difficult, but possible when further categorising each location into an approximate area on the cranium. These areas included the anterior portion, which is visible from the front of the skull, the posterior portion, visible from the back of the skull, and the superior portion, which can generally be seen from above the skull.

Within the Peru sample, a majority of trepanations were performed on the superior portion of the cranium (47%, tab. 6). This was followed closely by posterior-located trepanations (34%, tab. 6). Superior trepanations also occurred the majority of the time within the Southern Russian data (76.9%), and were similarly followed by posterior-located trepanations at 15.4% (Gresky *et al*. 2016, 670). This pattern was not reflected in the other regions, indicating posterior-located trepanations were the most common within Italy, at 58% (Giuffra & Fornaciari 2017, 758), Britain, at 59.3% (Roberts & McKinley 2008, 62), North America, at 57.2% (Stone & Miles 1999, 1016), and Anatolia, at 61.9% (Erdal & Erdal 2011, 533; 534). In all regions, apart from Southern Russia and Peru, anterior-located trepanations were the second most frequent in the collected samples. This suggests that regions which often trepan on the lateral sides of the cranium show less of a preference for midline, suture-related trepanations.

5.3.3. Biological Profiles

The biological profiles of the trepanned include sex estimations of the individuals, as well as age-at-death estimations. Sex estimations separate the proportions of males, females and those of indeterminate sex within the sample. Those deemed 'indeterminate' could have also been in either the male or female category, or within the subadult category. The age-at-death estimations include five categories, each containing a range of ages. These categories include sub-adults (0-17 years old), young adults (18-25 years old), middle adults (26-45 years old), old adults (46 years and above) and the adult category, which has an unknown age range between 25-46 years and above. The age-at-death estimation can potentially inform us of the age-of-trepanation, but it is assumed that this is only possible in Stage 0 and Stage 1 cases.

Within the sex-estimations of the Peru sample, the majority of trepanned individuals were identified as male (61%, tab. 8). The same majority of males can also be seen in most of the other regions in the comparison groups. These regions include Anatolia, at 65% (Erdal & Erdal 2011, 533; 534), Italy, at 74%

(Giuffra & Fornaciari 2017, 747; 748; 749) and Britain, at 64.5% (Roberts & McKinley 2008, 61). The outliers to this trend can be found in the Southern Russian and North American sample. Southern Russia had an equal proportion of male and female individuals who were trepanned, both representing 46.5% of the sample (Gresky *et al*. 2016, 669). This is potentially due to the small sample size (n=13), but does suggest the division was more equal than in Peru, Anatolia, Italy and Britain. The North American sample showed the same proportion of male individuals (36.8%) as indeterminate individuals (36.8%), which prevents a clear division between the sex estimations (Stone & Miles 1999, 1016). Generally, the comparison groups show that the preference to trepan males, as found within Peru, is not an isolated phenomenon.

The age-at-death estimations in Peru ranged from subadults to old adults, but were mostly concentrated in the middle adult age group (44%, tab. 9). Very few trepanned subadults were found in Peru, constituting 4% of the total sample (tab. 9). The lack of subadults is also reflected in Italy, at 3.7% (Giuffra & Fornaciari 2017, 757), and in Southern Russia, at 7.7% (Gresky *et al*. 2016, 669) – and no evidence of trepanned subadults were found in the Anatolian (Erdal & Erdal 2011, 533; 534), the North American (Stone & Miles 1999, 1016) or the British samples (Roberts & McKinley 2008, 61). Three out of the five comparison regions had a similar majority in the middle adult age category, as it was found in the Peru sample. These regions include Italy, at 32% (Giuffra & Fornaciari 2017, 757), North America, at 36.3% (Stone & Miles 1999, 1016) and Southern Russia, at the highest majority with 61.5% (Gresky *et al*. 2016, 669). As mentioned previously, this does not indicate that middle adults were more likely to be trepanned, but that most middle aged trepan subjects died shortly after the procedure. This could be directly related or entirely independent from the trepanations. The clearest trend that can be seen from these comparisons is the overwhelming minority of trepanned subadults, regardless of geographical location.

5.3.4 Survival Rates of Trepanation

Survival, as it was defined in Chapter 4, can be short (Stage 1) or extensive (Stage 2). Stage 1 survival can indicate between one to four weeks of recovery, before succumbing to infection or a related cause of death. Stage 2 survival indicates a longer period of time, potentially between multiple months to multiple years. Such healing rates vary between each individual. Ideally, the definition of survival should ultimately include only Stage 2 healed trepanations, but due to the difficulties that can come with identifying the state of recovery – any prolonged signs of survival are counted. Therefore, the final survival percentage comparisons were created by combining the rate of Stage 1 and Stage 2 healing. It should also be remarked upon that post-mortem trepanations are often classified in datasets as Stage 0 trepanations, which is correct, but misleading to the final survival estimate.

Among the data of six regions, neither region reported a majority percentage of Stage 0 healing, suggesting that survival or some form was most common within these data samples. Extraordinarily, the most common outcome for every region was extensive, Stage 2 survival – of which North America presented the highest at 89.5%. However, the rate of Stage 2 healing may been over-exaggerated due to the lack of Stage 1 identification. Both of the North American and the British studies did not disclose how complete the 'healed' trepanations were – making it impossible to determine a Stage 1 category. In spite of this, Britain continued to present the third lowest proportion of healing (60%, tab. 21).

The proportion of trepanations in Peru which showed no signs of healing equalled 29% (tab. 21). This was not the lowest occurring outcome, with the lowest being Stage 1 healing (18%, tab. 21). This suggests that the individuals within the Peruvian sample were more likely to die during, or shortly after surgery than to die during the first stages of healing and recovery. This is also seen in Italy and Southern Russia – but not in Anatolia. In Anatolia, the second most common of the three outcomes was Stage 0 healing (40%, tab. 21).

*Table 21: Frequency percentages of healing stages within Peru and the five comparison regions. *Total survival rate is derived from the combination of Stage 1 and Stage 2 healing – indicating short and long term survival. Data for Stage 1 was not available for Britain and North America.*

		Region					
		North America	Italy	Southern Russia	Peru	Britain	Anatolia
Healing Stage	0	10.5%	12.9%	15.4%	29%	40%	40%
	1	-	19.1%	23%	18%	-	7.5%
	2	89.5%	68%	61.6%	54%	60%	52.5%
	Final Survival Percentage*	**89.5%**	**87.1%**	**84.6%**	**72%**	**60%**	**60%**

Table 21 shows the regional proportions of all outcomes, as well as the final survival percentages in the bottom row, given in descending order. It can be seen in this table that Peru's final survival percentage of 72% is on the lower side of the spectrum, in comparison to the other five regions. When viewing survival in relation to the techniques used, it is unsurprising that Anatolia is within the lowest survival percentage – due to the most common technique of drilling and boring amounting to 45% of the sample (Erdal & Erdal 2011, 511; 518). North America, who showed the highest survival rate of 89.5% (tab. 21), did not record the methods of trepanation. Therefore, it cannot confirm whether this was influenced by a majority use of the scraping method, which has been theorised as having a correlation with higher survival rates. Although, the second highest survival rate, found in Italy (87.1%, tab. 21), did use show uses of scraping in 40.7% of the trepanations (Giuffra & Fornaciari 2017, 758). Peru demonstrated uses of scraping within 35% (tab. 3) of the sample, perhaps suggesting if scraping was more commonly used, the Peruvian survival rate may have increased.

However, the multitude of factors that may influence whether an individual will survive their trepanation – either for a long or short amount of time – are insurmountable with the current amount of data. Future attention should be paid towards the relationship between the survival rate and the method of trepanation in order to determine its level of impact. As the data stands, it can be known that from Peru and the comparative regions, survival ranges between 89% - 60%, with an average of 75.5% survival. This places Peru closely to the average survival statistic.

5.4. Possible Reasons for Ancient Peruvian Trepanning

Although it is not the focus of this thesis, the characteristics as well as the survival rate of trepanation in Pre-Columbian Peru is inherently linked to the motivations behind the practice. There is an absence of documentary evidence (González-Darder 2017, 37) as to why cases of trepanation are seen throughout the history of Peru which has led many researchers to theorise individually. The majority of these theories can be summarised as either ritual, medical or surgical theories. Though, it is beneficial to discuss as it can provide an insight into why such a hazardous procedure was attempted.

Trepanation theories revolving around rituals and ancient religious beliefs are perhaps the most elusive to 'prove' due to the cultural elements that lead to ritualistic behaviour. These cultural elements can often not be understood by someone so far removed from the society, and therefore makes it difficult to realistically understand the motivations behind this practice. Elferink (2015), who looked at the role of medical practitioners in the Inca Empire, claimed that the Inca people understood disease to be "the result of a disturbed relationship with supernatural forces" (Elferink 2015, 325). Therefore, it has been said that this ontology impacted the way they medically dealt with health issues – namely with "a strong involvement of religion and magic" (Elferink 2015, 327). It is through this line of logic that a jump is often made to deduce the reasons for trepanation. The release of spirits, or to remove sin from the body is then said to be religious motivators for trepanation in ancient Peru.

Medical and surgical reasons for Peruvian trepanation have become more widespread and generally more accepted as more studies suggest a high survival rate was achieved. Lovell (1997) has assumed that the effects of trauma on the cranium could have motivated the use of trepanation in Pre-Columbian Peru (Lovell 1997, 157). The displacement of bone fragments, depressed fractures or soft tissue damage could prompt the complete or partial removal of bone flaps to relieve the negative effects of trauma. Comparatively, modern neurosurgical cases see raised intracranial pressure – which occurs simultaneously with the swelling of the brain after injury – as an indication to perform a trepanation (Weber & Wahl 2006, 537). Andrushko & Torres studied the link between violence in Cusco and cranial trauma, finding that trepanations occurred in 21 individuals in association with minor cranial trauma (Andrushko & Torres 2011, 368). This same association with cranial trauma was also reported by Kushner *et al.* (2018), concluding that the treatment of head injuries was the "main reason for the evolution of cranial surgery". Alternatively, for every trepanation associated with cranial trauma, there are more that were not. This was especially the case in the Inca period, with Kushner *et al.* (2018) reporting nearly 90% of Inca-dating trepanations having different causes (Kushner *et al.* 2018, 250).

It is perhaps the case that trepanation began as a medical response to cranial trauma but continued to evolve over time into something much more culturally linked to tradition. Ultimately, the reality was likely that trepanations were performed for multiple reasons, many of which we will not be able to know without documentational evidence to confirm our theories.

6. Conclusion

This thesis aims to define the characteristics of trepanations within in Pre-Columbian Peru in order to understand the nature of the practice. In addition to this, it aimed to calculate the survival rate for this practice, and compare it to other survival rates calculated in this region and era. Both of these aims were met, and comments were made on the constrictions that arose when attempting to answer questions on a practice where little is known.

6.1. What were the characteristics of trepanation in Pre-Columbian Peru?

It was found that in regards to the nature of the trepanations observed, the majority of trepanations were done by the method of scraping (35%, n=96), with the lowest occurring method in the sample being circular grooving (14%, n=96). The largely preferred location of these trepanations were on the midline of the superior portion of the cranium (47%, n=172). The most commonly occurring biological profile of trepanned individuals among all groups were males (61%, n=117) and were identified with an age-at-death of 26-45 years of age (middle adults). The disproportionate amount of older trepanned individuals increase to 68% when groups are further divided into 'young' (0-25 years old) and 'old' (26-46+) – however this may be because of an overabundance of these individuals found during excavation. The number of average trepanations per person was above 1 per person in each department, with Lima remaining inconclusive due to lack of data. Across the sample, there was an average of 1.5 trepanations per person, which was largely skewed by the high amount of trepanations seen in the Cusco sample. Alternative characteristics of ancient Peruvian trepanations likely included natural anti-sceptic medicines used to disinfect the area of trepanation. Isolated finds of suture needles and cotton bandages may indicate the toolkit used in this procedure was more intricate than previously thought.

6.2. What was the survival rate of trepanation in Pre-Columbian Peru?

In regards to the survival rate, the overall rate of long-term healing was calculated at 54% (n=136), which is comparatively lower than the results of other studies done in the region. This may have been due to the overrepresentation of individuals who date from earlier periods, between the Late Horizon to Late Intermediate Period. This may show a less developed display of the practice, thus displaying lower rates of survival. Alternatively, it may be a result of harsher survival criteria used in this thesis, labelling only those who had visible signs of long-term healing as surviving. When combining instances of survival, whether limited or extensive, this survival rate totals to 72%, which is more similar to the survival figures identified elsewhere. Cross-tabular analysis on the relationship between the method of trepanation and the survival rate was only available for the sites located in Apurímac and Amazonas. The result of this found that scraped trepanations were most likely to show long-term healing (38%, n=56) but could not be seen as conclusive due to the under-representation of linear cutting trepanations. Analysis was also done on the relationship between the location of trepanation and the survival rate, which was only applicable for the department of Amazonas. It was found that trepanning on the left side of the anterior portion of the cranium had the highest success rate (21.1%, n=19), but the results were ultimately inconclusive due to the small sample size.

Discrepancies between the data sets used in this thesis were accounted for, with some difficulties in regards to regional comparisons. Nevertheless, the ending results of this thesis sheds light on some of the surrounding factors that have not been looked at in great detail within the field of Peruvian trepanations.

6.3. Future Research

Issues involving survival criteria can be improved upon in future research with the increased use of imaging technology. Imaging technology is responsible for potentially better survival estimates as it enables the researcher to make a more informed decision about the condition of the individual after trepanation. Chenge *et al.* (1996) examined the mortality of trepanation using three techniques – visual observation, radiography and CT scans (Chenge *et al.* 1996, 249). It was found in this study that both radiography and CT scans increased the accuracy and ease of identification of new bone formation associated with healing. It also revealed cases of porotic hyperostosis and trauma possibly associated with the trepanation – which could not be seen with the naked eye. (Chenge *et al.* 1996, 255). However, a current limitation to this technique remains to be the inability to distinguish between post-mortem and ante-mortem trepanation (Chenge *et al.* 1996, 258). With the rapid rate of development in this field, it is possible that the employment of newer imaging methods can enable researchers to surpass the confusion created between post-mortem trepanations and the '0' healing stage.

In addition to this, access to more data from the sample articles has the potential to lead to improved research in the future. Due to the lack of data available, connections could not be made between the survival rate and the location or method of trepanation. Besides access to more data, working with the skeletal material itself also has the potential to improve further research in this field. This would add more data to an already large data set of Peruvian trepanation, and could lead to a larger sample size thereby leading to a greater validated hypothesis.

7. Abstract

In this study, a selection of articles on trepanation in Pre-Columbian Peru were chosen to represent the four departments of Amazonas, Apurímac, Lima and Cusco. The available data was extracted from these articles, and combined in order to greater understand the variations between the method, location, biological profiles and frequency of trepanations in Peru before the Spanish conquest. The survival rate for this sample, at 54% (n=136), suggests a lower rate than shown in previous studies. This result is discussed, in relation to surrounding issues within trepanation studies to understand the true implications of the results. The lack of available data, as well as the future improvements imaging technology encourage for further research into the subject of survival and the nature of Peruvian trepanations, hopefully exceeding the problems encountered in the making of this study, as well as previous studies, on trepanation.

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Figures

Tables