# Observable Stages and Scheduling for Alveolar Remodeling following Antemortem Tooth Loss

Dissertation

Zur Erlangung des Grades

Doktor der Naturwissenschaften

Am Fachbereich Biologie

der

Johannes Gutenberg-Universität Mainz

Dissertation

for the Acquisition of the Degree

Doctor of Natural Sciences

Biology Faculty

of the

Johannes Gutenberg-University Mainz

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[redacted]

Mainz, 2011

[redacted]

Date of defense: 19 August, 2011

For my father

- who first introduced me to archaeology -

- and who has encouraged me to bore him about teeth for the past five years -

for being the first to inspire me

*ad infinitati et ultra*!

## ABSTRACT

Antemortem tooth loss (AMTL) is the end stage of archaeologically visible dental disease, a side effect of progressed stages of scurvy and leprosy, intentional or unintentional due to trauma and ablation, or the result of extreme continuous eruption. Bone eventually fills the socket but the time required for this to occur, along with macroscopic appearance during this process, is unclear. Because of the frequency of AMTL a schedule to assess time since tooth loss (TSL) from macroscopic observation of dry bone would be of use to osteoarchaeology and forensic science and some merit to general dentistry and implantology.

After tooth loss soft tissue occupies the socket; this is quickly converted to immature bone which stabilizes the jaw and neighboring teeth and then remodeled to appear identical to the surrounding alveolus. The appearance and fullness of the socket throughout this process, as identified via radiograph in living individuals and applied to archaeological remains through gross observation, undergo distinguishable stages. Socket healing can be divided into pre-osseous (within one week of tooth loss), bony remodeling (approximately 14 weeks since loss), and ossified/healed (at least 29 weeks since loss) stages. Several variables however – such as interdental ridge resorption, internal socket appearance, and sex, among others – have statistically significant accelerating or inhibiting effects on this normal rate of remodeling, diverging up to 19 weeks from this base rate. Many other variables were found to have insignificant relationships with TSL despite diverging from the base rate. Some inter-variable relationships were also tested regardless of fullness, and groups of independent variables were assessed with stage of fullness and TSL in

multivariable models. With these results simple TSL estimation in weeks is possible from socket fullness with increased precision attained with some additional observable data.

Although various types of dental disease were taken into consideration, future investigation should focus more on this potential interference; the links between causation and correlation of some variables (such as neighboring tooth presence or clinical treatment) with acceleration or inhibition of socket healing rate would be of relevance to further investigation of bony oral tissue dynamics. Studies with an autopsy sample with known TSL or a progressive rather than retrospective clinical sample would provide useful confirmation of these results.

## ZUSAMMENFASSUNG

Zahnverlust zu Lebzeiten („antemortem tooth loss“, AMTL) kann als Folge von Zahnerkrankungen, Traumata, Zahnextraktionen oder extremer kontinuierlicher Eruption sowie als Begleiterscheinung fortgeschrittener Stadien von Skorbut oder Lepra auftreten. Nach dem Zahnverlust setzt die Wundheilung als Sekundärheilung ein, während der sich die Alveole mit Blut füllt und sich ein Koagulum bildet. Anschließend erfolgt dessen Umwandlung in Knochengewebe und schließlich verstreicht die Alveole derart, dass sie makroskopisch nicht mehr erkannt werden kann. Der Zeitrahmen der knöchernen Konsolidierung des Kieferkammes ist im Detail wenig erforscht. Aufgrund des gehäuften Auftretens von AMTL in menschlichen Populationen, ist die Erarbeitung eines Zeitfensters, mit dessen Hilfe durch makroskopische Beobachtung des Knochens die Zeitspanne seit dem Zahnverlust („time since tooth loss“, TSL) ermittelt werden kann, insbesondere im archäologischen Kontext äußerst wertvoll. Solch ein Zeitschema mit

Angaben über die Variabilität der zeitlichen Abläufe bei den Heilungsvorgängen kann nicht nur in der Osteologie, sondern auch in der Forensik, der allgemeinen Zahnheilkunde und der Implantologie nutzbringend angewandt werden.

Nach dem Verlust eines Zahnes wird das Zahnfach in der Regel durch ein Koagulum aufgefüllt. Das sich bildende Gewebe wird rasch in noch unreifen Knochen umgewandelt, welcher den Kieferknochen und auch die angrenzenden Zähne stabilisiert. Nach seiner Ausreifung passt sich das Gewebe schließlich dem umgebenden Knochen an. Das Erscheinungsbild des Zahnfaches während dieses Vorgangs durchläuft verschiedene Stadien, welche in der vorliegenden Studie anhand von klinischen Röntgenaufnahmen rezenter Patienten sowie durch Untersuchungen an archäologischen Skelettserien identifiziert wurden. Die Heilungsvorgänge im Zahnfach können in eine prä-ossale Phase (innerhalb einer Woche nach Zahnverlust), eine Verknöcherungsphase (etwa 14 Wochen nach Zahnverlust) und eine ossifizierte bzw. komplett verheilte Phase (mindestens 29 Wochen nach Zahnverlust) eingeteilt werden. Etliche Faktoren – wie etwa die Resorption des Interdentalseptums, der Zustand des Alveolarknochens oder das Individualgeschlecht – können den normalen Heilungsprozess signifikant beschleunigen oder hemmen und so Unterschiede von bis zu 19 Wochen verursachen. Weitere Variablen wirkten sich nicht signifikant auf den zeitlichen Rahmen des Heilungsprozesse aus. Relevante Abhängigkeiten zwischen verschiedenen Variabeln wurden ungeachtet der Alveolenauffüllung ebenfalls getestet. Gruppen von unabhängigen Variabeln wurden im Hinblick auf Auffüllungsgrad und TSL in multivariablen Modellen untersucht. Mit Hilfe dieser Ergebnisse ist eine grobe Einschätzung der Zeitspanne nach einem Zahnverlust in

Wochen möglich, wobei die Einbeziehung weiterer Parameter eine höhere Präzision ermöglicht.

Obwohl verschiedene dentale Pathologien in dieser Studie berücksichtigt wurden, sollten zukünftige Untersuchungen genauer auf deren potenzielle Einflussnahme auf den alveolaren Heilungsprozess eingehen. Der kausale Zusammenhang einiger Variablen (wie z. B. Anwesenheit von Nachbarzähnen oder zahnmedizinische Behandlungen), welche die Geschwindigkeit der Heilungsrate beeinflussen, wäre von Bedeutung für zukünftige Untersuchungen des oralen Knochengewebes. Klinische Vergleichsstudien an forensischen Serien mit bekannter TSL oder an einer sich am Anfang des Heilungsprozesses befindlichen klinischen Serie könnten eine Bekräftigung dieser Ergebnisse liefern.

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# CHAPTER 1 INTRODUCTION

When teeth are lost or removed intra vivam the bony socket models and remodels over time so that there is no longer a cavity. Although the healing process following antemortem tooth loss (AMTL) is known both clinically and histologically, it has never before been approached from a physical anthropological perspective. The primary purpose of this research is to assess the length of time from the incident of tooth loss until a socket attains specific stages of healing – as defined by certain characteristics such as appearance and fullness – and the application of these findings to estimate time since tooth loss (TSL) in osseous human remains. This will be undertaken by observing the radiographic and written records of recent patients from a dental surgery in Germany in conjunction with gross observation of dry mandibles and maxillae of individuals from three archaeological assemblages from medieval Germany and England. Various simple and complex statistical analyses will be utilized in order to more accurately and precisely define stages of healing and factors which either increase or decrease the rate at which healing occurs. Secondary objectives consist of reviews of the practice of dental ablation, factors influencing bone remodeling in general and alveolar remodeling in particular, and the different causes of AMTL. These will be met through a comprehensive preliminary literature review.

The applications of this research are myriad but largely osteoarchaeological. The estimation of TSL may be utilized to interpret a minimum length of time since the climax of severe dental disease or at what age an individual lost a tooth due to trauma or intentional removal. Interpretations from such data have value for archaeological contexts for the assessment of ablation, interpersonal violence, and dental disease. Such findings will be novel in physical anthropology as socket healing has not before been investigated in such a manner. Other disciplines, such as forensic odontology (as an additional method of identification), clinical dentistry (where previous records are not available), and implantology (to help plan treatment timelines), may also have use of the results.

In spite of such lofty aims even the most ideal results will have limitations, largely where reliability and population variation are concerned. Osteoarchaeological standards are usually too imprecise for clinical purposes and so findings may not provide a real improvement on previous studies which both utilize such standards and take soft tissue healing into consideration. In terms of population variation although the archaeological assemblages selected are somewhat genetically divergent they are of course not representative of more varied populations and different ethnic groups. Although various bone remodeling studies indicate disagreement between genetically dissimilar populations should be minimal, at least at the level of precision employed by the following methodology, population bias is still a consideration of any practical application of the results.

## 1.1 Why AMTL?

Teeth are fascinating. As specialized, modified bony elements they are subject to the same scrutiny as the rest of the skeleton by physical anthropologists in terms of development, pathological and physiological changes, and variation. Their display indicates certain moods and threats and they are used for grooming, as tools, and for mastication and consumption. As semi-visible aspects of human anatomy with compartmentalized sensory nerves they are also subject to all manner of filing, drilling, scoring, dyeing, and various other permanent and temporary modifications. Dental health specialists are endemic in modern western societies and disease prophylactic aids and appliances in various forms are found in virtually every household. In large part because of the need for a functional dentition in order to eat and thus live teeth have also captured the attentions of those who study humans and human behavior in the past. Sex estimation, developmental and attritional age estimations, dietary reconstruction, and destructive analyses to determine isotopic values and biochemical composition are all assessed with or performed on teeth. Where modification is concerned however there is considerably less investigation into teeth as osteoarchaeology continues to edge away from ethnographic and behavioral foci and further into the biological sciences. As the final stage of severe dental disease or physiological adaptation AMTL falls solidly within this latter category but where it results from trauma or intentional removal it is an aspect of the former, neatly bridging both biological and psycho-sociological investigations of past peoples and so of interest to disciples of a multiple subjects. Study of this small subset of dental anthropology is entirely interdisciplinary and conclusions without regard for all possible data are negligent.

The following research has been performed and presented from such an interdisciplinary stance. Although the anatomical findings would easily be applicable to purely biological anthropological contexts they are best interpreted with regard to physiology, health, *and* behaviors of past populations. In addition, a considerable part of the background research is of ethnographic interpretations of osteoarchaeological (and clinical) data, but without the interdisciplinary framework from which to approach socket healing and so only sufficient for the formation of limited conclusions.

As with all studies, the initial investigation is of a literary nature. Perusal of relevant dental, medical, forensic, anthropological, and archaeological publications from the past few decades (and occasionally beyond) yielded considerable data which required careful analysis in order to ensure its relevance and applicability to an osteoarchaeological study. Various source biases are present throughout this body of literature. Perhaps what is most desired from this aspect of the project is the reconsideration of AMTL in osteoarchaeology. Only through a large-scale study is it possible to better define AMTL from causes and effects to the limits and capabilities of current techniques and recent studies.

*Source consolidation and bias*

Source bias affects everything from project design, data collection, and data presentation to final conclusions drawn. Clinical dental trials for example pay little or no attention to the appearance of remodeling bone patterns; studies on bone turnover dynamics usually only mention the alveolus in passing, focusing instead on larger weight-bearing elements; historical or cultural anthropological records of tooth ablation often neglect prevalence and long-term effects. In addition to the usual problems that plague osteoarchaeology – biases on the parts of population variation, sample size, preservation, and others – a lack of organized and reliable published research leaves future projects without a more concrete foundation upon which to rely. This project and its results and their presentation will themselves be biased as a source: although certain aspects of the findings are expected to be relevant to both forensics and dentistry in addition to osteoarchaeology the way in which they are attained, described, and presented will be most useful to the latter discipline. Additional subjects for which the results may be of some interest –

zooarchaeology, paleoanthropology, medicine, cultural anthropology, etc. – have not been especially been catered to. The primary intended application medium of this research has resulted in various concessions which are most obvious in the broad groupings of individuals' ages and less precise time since loss (TSL) durations than could have been calculated. It is likely that these are too imprecise for immediate or unadulterated clinical or forensic application, in which case it is hoped the project model and its successes and failings may at least serve as a guideline should more exact time spans be desired.

Perhaps in large part due to the inherent biases of relevant past research, a comprehensive treatment of AMTL in general is somewhat lacking in osteoarchaeology in comparison to such treatments of caries or dental age estimation. Discussion of non-pathological factors as causes of tooth loss in this field has been restricted to occasional papers on trauma (Lukacs 2007), continuous eruption (Danenberg et al. 1991), and ablation (Han and Nakahashi 1996; Hrdlička 1940; Robb 1997). In related disciplines however rates of tooth loss have been found to be significant with regard to osteoporosis and menopause (Mohammad et al. 2003; Nicopoulou-Karayianni et al. 2009), various traumas (Birgen et al. 1999; Wright et al. 2007; many others), and hypo- and hypercitricemia (Leggott et al. 1991; Tsunemitsu et al. 1963); further studies on some modern dental practices indicate previously unknown reasons for and instances of tooth removal (Graham et al. 2000; Wolf 1996) as well as information on early modern extraction methods (Atkinson 2002; Chiu and Davies 1998). Although interdisciplinary research is commonplace in osteoarchaeology, the lack of comprehensive inclusion of this topic – a combination of physiology, pathology, trauma, and intentional modification – within the osteoarchaeological literature is unfortunate. Due to this current work being novel in many respects in this field – both as an interdisciplinary investigation as well as consisting of a unique research plan and the collection of new data – it is subject to the same problems inherent in all such osteological studies, largely this lack of similar studies with which to either compare results or pool the data.

## 1.2 Tooth Loss as an Indicator

In archaeological remains, AMTL is frequently recorded because of the potential for interpretations of dental disease and, to a lesser extent, intentional body modification. Indicators of dental disease are an integral part of a holistic approach to paleopathology. Caries, severe attrition, and calculus can, through subsequent periodontal disease, all eventually result in tooth loss through the destruction of osseous support and the tooth itself. Although not all of these pathological processes will result in AMTL they are largely limited only by the individual's lifespan. Such disease indicators are so significant not simply because they are common and identifiable but also because their processes are well understood. Caries epidemiology is a key subject in dentistry and investigated through many and varied clinical trials. Periodontal disease and plaque are similarly examined due to their influences on modern dental health and systemic health. Alveolar remodeling and residual ridge resorption are crucial topics in implantology, where osseous structural integrity is critical to successful procedures. The result of such foci is that oral disease and their epidemiologies, progressions, and effects on the bony oral tissues are intensively and extensively investigated to the standards of modern medicine.

Dental disease is also an indicator of diet or certain behaviors. Irregular attrition for example is sometimes attributed to use of wooden toothpicks or fiber processing; if severe enough to expose the pulp cavity, pulpitis and alveolar osteomyelitis[1] may occur as a result (Alt and Pichler 1998; Formicola 1988; Schulz 1977). Calculus is primarily managed through mastication, non-masticatory tooth use, and mechanical oral hygiene activities (brushing, flossing, and similar) (Lieverse 1999; White 1997). Diet may be similarly inferred: regular attrition is largely dependent on diet composition and varies depending on primary foods (Littleton and Frohlich 1993; Scott 1979). For calculus however the link to diet is less certain, with contradictory studies finding significant accumulations in individuals with diets high in either protein or carbohydrates (Lieverse 1999; White 1997). Caries are the result of localized enamel demineralization by bacterial adhesions, the colonization of which is encouraged by a diet high in carbohydrates (Hillson 2001).

Other behavioral interpretations of AMTL include ablation or trauma, where ablation is defined as intentional tooth removal. Although all methods of tooth removal are traumatic to the tissues involved intention is what distinguishes ablation from avulsion. Traumatic avulsion, luxation, or sublaxation occurs with varying prevalence throughout the world but substantially more frequently among some populations and subgroups, particularly children and athletes (Al-Majed et al. 2001; Kumamoto et al. 1997). Ablation is performed for a number of reasons and by diverse methods throughout the modern and ancient world.

*Reconstruction of disease*

Despite being caused by both pathological and non-pathological processes, AMTL is most frequently identified as resulting from alveolar osteomyelitis due to penetrative caries (Alt

[1] The term "alveolar osteomyelitis" refers specifically to the destructive changes to the alveolus due to bacterial infiltration beyond the crest, the appearance of which is similar to that of osteomyelitic changes elsewhere in the skeleton. Although such a defect is usually designated an "abscess" or "alveolar defect of pulpal origin" these terms are misleading as the defect may have been cause by an abscess, cyst or granuloma and result from pulpitis, enamel defect, or tooth or alveolar fracture.

et al. 1998; Hillson 2001). This pathological process usually manifests as a furcal or apical alveolar defect as a direct result of bacterial infiltration via the pulp cavity initiated by pulp exposure due to penetrative caries, severe attrition, developmental defects, or tooth or jaw fracture (Clarke and Hirsch 1991a; Clarke et al. 1986; Hillson 2001). A high individual or group AMTL rate coupled with the most common precursors to alveolar osteomyelitis – or actual alveolar defects – indicates tooth loss is most likely pathological (see Table 1.2.1). A diagnosis of periodontitis as the cause of tooth loss may be similarly entertained or excluded. Periodontitis, an infection of the alveolar crest, develops as a result of bacterial penetration of the alveolar crest most often due to subgingival calculus or, occasionally, trauma or developmental defects (Costa 1982; Clarke and Hirsch 1991a; Hillson 2001; Pihlstrom et al. 2005). A high AMTL rate in conjunction with the presence of either profound periodontitis and/or considerable subgingival calculus and the absence of osteomyelitic defect may indicate periodontitis is responsible.

Continuous eruption however is not a pathological reaction but a physiological one (Alt and Rossbach 2009; Clarke and Hirsch 1991a; Danenberg et al. 1991; Glass 1991; Hillson 2001). Although AMTL from continuous eruption is deemed to be relatively infrequent as it rarely occurs to such an extreme, it is still a legitimate non-pathological explanation (Clarke and Hirsch 1991b; Danenberg et al. 1991; Hillson 2001). Unfortunately one common method utilized to determine degree of periodontal disease – that of increased distance between the cemento-enamel junction and alveolar crest being indicative of marked pathological crestal resorption – is in fact more likely to illustrate the rate of continuous eruption (Ainamo 1978; Danenberg et al. 1991; Glass 1991; Levers and Darling 1983). Because this method has been utilized not infrequently (as in Eshed et al.

2006, Lavelle 1973, Tal 1985, and others), the prevalence of periodontal disease in past populations is often exaggerated; with correct diagnosis it will be possible to better understand what role continuous eruption realistically plays on tooth retention.

**Table 1.2.1 Profiles of Common Causes of AMTL in Archaeological Samples**

| High AMTL | Low AMTL | Frequent/severe alveolar osteomyelitis | Rare/mild alveolar osteomyelitis | Many/penetrative caries | Few/non-penetrative caries | Pulp-exposing/severe attrition | Attrition does not expose pulp | Periodontitis | No periodontitis | High CEJ-AC | Normal CEJ-AC | No other disease indicators | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | | X | | X | | | X | | X | | | X | Pathological AMTL caused by pulpitis by caries |
| X | | X | | | X | X | | | X | | | X | Pathological AMTL caused by pulpitis by attrition |
| X | | X | | | | | | | X | | | X | Pathological AMTL cause by pulpitis by indeterminate origin |
| X | | | X | | X | | X | X | | X | | X | Pathological AMTL caused by periodontitis |
| X | | | X | | X | | X | | X | X | | X | Non-pathological AMTL caused by continuous eruption |
| X | | | X | | X | | X | | X | | X | | Pathological AMTL caused by non-dental pathology |
| | X | | | | | | | | | | | | External cause of AMTL (avulsion or ablation) |

Suggested diagnostic indicators of various pathological causes of AMTL. CEJ-AC refers to the distance between the cemento-enamel junction and the alveolar crest.

Finally there is the consideration of non-dental pathologies which nonetheless affect tooth retention. Rhinomaxillary syndrome resulting from leprosy is of course well known both historically and in the archaeological record as being a cause of anterior maxillary tooth loss (Roberts and Manchester 2005). Scurvy however presents somewhat more of a problem: although historically associated with tooth loss, it is less frequently and reliably identified in osseous remains as the indicators for this condition are similar or identical to those of other pathologies and dietary deficiencies (Aufderheide and Rodríguez-Martín 1998; Roberts and Manchester 2005). In addition there is the question of how much scorbutic changes truly affect tooth retention: usually once the disease reaches such an advanced stage death is imminent and associated tooth loss identified as peri- or postmortem (Aufderheide and Rodríguez-Martín 1998; Hunt and Paynter 1959). In addition various clinical trials have shown that, while considerable attachment loss does occur, it is not enough to cause tooth shedding except where periodontal disease is exacerbated by the deficiency (Aufderheide and Rodríguez-Martín 1998; Hunt and Paynter 1959; Leggott et al. 1991; Tsunemitsu et al. 1963). It may be that when teeth became loose due to vitamin C deficiency in the past they were removed or lost through mastication; conversely, it is possible that the shedding of teeth was simply not as common as historical sources indicate. Finally sinusitis, although not traditionally associated with tooth loss, in a severe form may cause a local osseous reaction which insufficiently supports the related maxillary teeth. It should however be noted that although sinusitis is correlated with dental disease it has not been studied with particular regard to tooth loss (Panhuysen et al. 1997).

*Reconstruction of behaviors*

Dental modifications, from filing to painting to ablation, are not particularly unusual in the past or present (Alt and Pichler 1998; de la Borbolla 1940; Milner and Larsen 1991; Pindborg 1969; many others). Tooth ablation in past populations is currently most often identified due to distinguishable patterns: the removal of mirroring anterior teeth (such as both maxillary canines) being the most common (Han and Nakahashi 1996; Hrdlička 1940; Kusaka et al. 2008; Tayles 1996). Historical sources however indicate this only sometimes occurs and so it is reasonable to assume numerous prehistoric cases are invisible to the current selection criteria (Flood 2006; Merbs 1968; Pietrusewsky and Douglas 1993; Wolf 1996). By better understanding when AMTL is pathological and when it is not such cases are more likely to be detected and so allow a better understanding of the respective societies and their customs.

Unintentional trauma is also influenced by behavior. Published accounts indicate basketball players and participants in equestrian activities for example to be particularly susceptible to avulsion and blunt force trauma due to interpersonal aggression and accidents (automobile collisions, falls, etc.) is also a primary cause in modern populations (Birgen et al. 1999; Kumamoto et al. 1997; Martins et al. 2006; Wright et al. 2007). In archaeological assemblages some headway has been made by Lukacs (2007; with Hemphill 1990) but these examples are from limited population samples and lack broader contexts for comparison. His solo paper (2007) however goes into the details of specific known competitive physical activities in which the population participated as well as referring to the dental health of the individuals. For populations known to participate in rigorous physical behaviors or engage in frequent interpersonal combat rate of AMTL is not necessarily a pathological indicator but instead may be one of trauma.

*Reconstruction of diet*

Indicators of oral pathologies are also often indicators utilized in the reconstruction of diet. Before isotope analyses there were attritional patterns, caries rates, and calculus accumulations (Caselitz 1986; Duckworth and Huntington 2006; Hillson 1979, 2001; Lieverse 1999; Lussi et al. 2004; Teaford 1988). Diets high in carbohydrates, for example, have higher rates of alveolar osteomyelitis in molars due to penetrative caries (Hillson 1979, 2001; Littleton and Frohlich 1993; Lukacs 1992). Sugary fruits are particularly damaging to the dentition in this regard: one study found AMTL in every individual, usually the first molar, in a location with plentiful dates and figs (Nelson et al. 1999).

Calculus accumulation patterns and severity can also contribute to the reconstruction of diet. Calculus is a combination of the calcification of a plaque biofilm and an accumulation of minerals precipitated from saliva, most of which are derived from the diet and oral flora, and only more recently has the long-suspected inverse relationship between calculus and caries – and so dietary composition – been tested (Christersson et al. 1992; Lieverse 1999; White 1997; Wilson 2008). Various experiments have found that although a diet high in protein produces a slightly more alkaline oral environment suitable for mineral precipitation, a diet with a substantial carbohydrate component encourages the bacteria which comprise the prerequisite plaque biofilm (Duckworth and Huntington 2006; Lieverse 1999; White 1997).

Assessing attritional dental wear in order to interpret diet is also not straightforward: the physical erosion occurs not only from the mastication of food but also contact with non-food items and utensils, from bruxism, and oral hygiene paraphernalia (Formicola 1988; Molnar 1972; Seligman et al. 1988). Pattern, intensity, and rate are most often utilized to estimate dietary composition, but, similar to caries, when considered as a cause of AMTL it is under the assumption that the tooth was lost due to alveolar osteomyelitis (Clarke and Hirsch 1991a; Clarke et al. 1986; Littleton and Frohlich 1993; Teaford 1988). Like calculus, attrition is also seen as having an inverse relationship with caries rates as wear can control the rate at which bacterial adhesions (which later develop into carious defects) occur; because of this there are many cases where tooth loss can be attributed to an alveolar defect which may have originally been caused by either severe attrition or penetrative caries (Hillson 2001; Maat and van der Velde 1987). Attrition and continuous eruption are also thought to occur concurrently as both are accumulative age-linked processes, but whether the latter is a response to or in anticipation of the former is as yet unknown (Danenberg et al. 1991; Glass 1991).

## 1.3 Practical Interpretations of Research

Practical applications of the individual and combined historical, radiographic, and osteological investigations are many and varied. In general any such extensive investigation into a realm of study enhances the knowledge and understanding of the subdiscipline and it is hoped that the comprehensive approach taken here will so contribute to general dental anthropology. Dental ablation has been studied ethnographically, clinically, and occasionally osteoarchaeologically, but rarely from an interdisciplinary approach. Modern western tooth extraction has occasionally been considered anthropologically with a view to historical progression although this is of value to medical history as well as cultural anthropology. The body of data consolidated on this practice is the most comprehensive of its kind and has already been disseminated at relevant conferences. The combination of these findings – which illustrate the prevalence and history of intentional tooth removal throughout time and all over the world – with the new osteological data is hoped to encourage the reconsideration of AMTL in past societies, particularly with regard to its cause. Research in and understanding of dental disease, body modification and related behaviors, and dental physiology is now such that AMTL need not be automatically assumed to be the result of severe dental disease except where it is clearly supported by the evidence (Glass 2001; Hillson 2001; Lukacs 2007).

A better understanding of socket healing over time in archaeological remains may assist in the identification of cause of tooth loss, such as where several individuals in an archaeological population are estimated to have lost teeth approximately three months prior, ablation may be inferred. Multiple individuals estimated to have lost teeth at approximately the same age may also be interpreted as having engaged in age-linked rituals, treatments, or other behaviors which either directly or indirectly led to tooth loss (as in Flood 2006, Han and Nakahashi 1996, and Hassanali and Amwayi 1993). The term age-specific loss mapping refers to the identification of age at the time of tooth loss for specific individuals within a larger assemblage; in conjunction with tooth loss distribution patterns within individual dentitions the resultant pattern may indicate tooth loss within a specific subgroup at a specific developmental/attritional, social, or chronological life stage. Although perhaps of greatest interest with regard to intentional ablation or other trauma, coupled with data on dental disease such a technique could provide a more comprehensive understanding of both the normal temporal progression of severe dental disease in the past as well as data on average age at onset for a given population.

In conjunction with this however are the related disciplines of dentistry, specifically implantology, and forensic odontology. Modern dentistry, particularly in developing countries with insufficient facilities or with new patients lacking prior dental records, may also benefit from improved methods of estimating duration of severe dental disease. Implantology in particular is completely dependent upon a practitioner's ability to (noninvasively if possible) estimate the composition, dynamics, and stability of the local alveolus following tooth loss. Although it is quite rare to attempt to identify named individuals in archaeological contexts this is at the heart of forensic anthropology. Incomplete or absent dental records however make this method of identification problematic and the ability to estimate TSL for a given socket can contribute to a fuller profile of an unidentified individual (Adams 2003; Pretty and Sweet 2001).

Forensic odontology is most frequently utilized to identify an unknown deceased individual. This is performed largely with three techniques: (1) the comparison of postmortem and antemortem dental records, radiographs, and restoration patterns; (2) the matching of recovered orthodontic and denture appliances with dentist's records or casts; and (3) the comparison of known teeth-altering behaviors during life – such as smoking or bruxism – and their evidence in the dentition (Adams 2003; Pretty and Sweet 2001; Rogers 1988; Rothwell et al. 1989; Whittaker 1995). In addition dental profiles and records are also often compared with recovered bite marks in flesh or other materials in order to confirm a suspect's involvement or presence in association with a crime (Souviron 2006; Vale 2004). Particularly in cases where complete dental records or radiographs are not available investigators are forced to rely on written or partial records or without comparative records entirely as in some cases of unidentified persons (Adams 2003; Pretty and Sweet 2001).

In addition a TSL estimate may also serve as a memory aide in addition to facial reconstruction sketches, age estimations, and physical descriptions. In cases of bite marks a radiographic analysis of the suspect's arch in conjunction with TSL estimation could indicate whether a tooth was likely present or not at the time the mark was made. This would be in addition to the usual methods of assessment (primarily casting impressions) and be of especial merit where the suspect is lacking teeth which left an impression or where the impression of certain teeth are missing from within the arch of the mark (Souviron 2006; Vale 2005; Whittaker 1995).

*Feasibility*

In addition to broader interpretations and applications the experimental stage will also be assessed for its methodologies. Critical review of the materials and methods employed will itself contribute to further investigation in the arena of dental anthropology. Questions of whether or not broad error margins can be practically reduced, if different or larger modern or past populations might produce more favorable results, or indeed if the aims of the project are too far-reaching will be addressed as they arise in the conclusion and discussion chapters. The most common (and most likely) such methodological insufficiencies are expected to relate to cohort size and demographics: statistical significance is incalculable with too small a sample size and a dataset skewed in the direction of males, for example, may be key to the success or failure of certain aspects of the following experiments.

A few of the published studies on this subject are concerned largely or solely with histological changes and these found great success in their approaches (Amler 1981; Cardaropoli et al. 2003; Grewe and Felts 1969; others). As histology is also commonly utilized for osteoarchaeological remains particularly to better understand specific bone changes and activity on a cellular scale, similar success is likely with the alveolus.

Unfortunately such an approach would be destructive and also require equipment, a working environment, and expertise not necessary for gross observational techniques, making the eventual results less practically applicable. Indeed the present experimental plan has been derived with the twin stipulations of maintaining sample integrity and utilizing standard radiographs (for the clinical cohort) and simple gross observation (for the archaeological cohort) in order to produce reliable and easily applicable results to both clinical and archaeological samples.

# CHAPTER 2 BACKGROUND

As with any study on oral and dental disease for osteological application, the publication body of related research is considerable and derived from dental, medical, forensic, anthropological, and archaeological sources. Although at this time no research of the exact nature of this dissertation has been performed there are several similar studies published from histological and clinical perspectives with both human and animal models (Adeyemo et al. 2006; Cardaropoli et al. 2003; Elsubeihi and Heersche 2004; Schropp et al. 2003; Trombelli et al. 2008). As the plan of this research includes a comprehensive study of observable alveolar remodeling in dry bone it is osseous socket healing which will be closely scrutinized but soft tissue changes, general bone remodeling, the state of the socket prior to and at the point of tooth loss, and systemic stressors will also provide additional information. Because clinical studies outside of dentistry are only rarely concerned with slight osseous responses of the oral cavity, correlations must be made for effects on oral soft tissues, non-oral osseous reactions, and effects upon processes which themselves affect oral osseous structures and their processes.

Soft tissue activity can but does not necessarily indicate related osseous changes: periodontal disease for example presents clinically with mild (gingivitis), moderate (periodontitis), and severe (osteomyelitis) symptoms but only the latter two provoke an osseous response (Clarke and Hirsch 1991a; Costa 1982; Socransky et al. 1984). Soft tissue trauma and hemorrhage are similarly unlikely to produce an osseous reaction (Roberts and Manchester 2005). Bone density, resorption, and remodeling have been popular subjects within physical anthropology and human biology as well as geriatrics and other medical branches. Although the medical studies tend to be from an endocrinological approach, the former also investigate the effects of mechanical stimuli, effects of age, and the significance of various diseases and conditions. Osteopenia and osteoporosis and their sequelae are common subjects in studies of the past and present and research on their effects on the skeleton have also been successfully applied to tooth loss (Binte Anwar et al. 2007; Costa 1982; Lerner 2006a).

Systemic stressors may produce a systemic osseous reaction but this is not always true: the identification of treponematoses in dry bone for example is based primarily on lesions on the tibiae and external cranial vault although the infection is a systemic one (Roberts and Manchester 2005). Nonspecific generalized stress however will retard growth functions systemically; the presence of Harris lines or enamel hypoplasia indicates that cellular bone modeling and remodeling was affected to the point of obvious growth retardation (Roberts and Manchester 2005). Unfortunately arrestation at the time of death will not be apparent from these clues which only provide information regarding previous periods of severe stress during childhood and adolescence, but evidence of systemic disease active at the time of death will be applicable (Roberts and Manchester 2005).

In addition to interpretations of correlations, the state of the socket at the time of tooth loss is also expected have an effect on the process and length of time before it has completely ossified. If the socket is smaller this will presumably result in less time required for full osseous healing of the socket; this is particularly applicable to single-rooted compared to multiple-rooted teeth as well as teeth lost due to overactive continuous eruption (supereruption). Where tooth loss is the result of active disease (osteomyelitis or periodontitis) the disease is likely to continue unabated and thus significantly delay socket healing (Hillson 2001). Complications which can result from either ablation or avulsion include alveolar osteitis, alveolar or jaw fracture, and tooth fracture which can leave fragments within the socket: these too will delay healing time (Adeyemo et al. 2007).

An awareness of the circumstances surrounding tooth loss and the ability to control for them if necessary is crucial to an assessment of TSL. To that end the type of tooth loss (extraction/traumatic, pathological, physiological) coupled with a consideration of systemic health in addition to the usual divisions by sex and age groups will provide the most reliable estimation techniques. As in all osteological investigations the specific region, in this case the socket, is not isolated from the rest of the individual and their biological processes and so must be analyzed with regard to the system as a whole.

## 2.1 Causes of Tooth Loss

Causes of tooth loss in vivo derive from pathological, physiological, and traumatic mechanisms or combinations thereof. Responsive external actions can also interfere with all three of these categories: a tooth may be removed or extracted due to increased mobility from hypereruption or pain associated with pulpal or alveolar infection (Hillson 2001). In addition diet, consumption and extra-consumption masticatory activities (eating as well as use of teeth as tools in fiber processing, cracking nuts, etc.), and general oral hygiene all have significant effects on the severity of general and local attrition and prevalence of dental disease both individually and within a given populace (Formicola 1988; Molnar 1972; Seligman et al. 1988).

The identification of the impetus by which a tooth is lost during life is not straightforward. Conclusions regarding extraction are heavily weighted by appearance and patterning within a single dentition as well as throughout a community, even though modern western extraction, for example, is performed for purposes of appearance but more often for disease treatment (Caldas 2000; Carranza and Takei 2006; Chestnutt et al. 2000). As discussed above, continuous eruption is frequently misidentified as periodontal disease due to an erroneous (yet persistent) method for assessment of the latter (Danenberg et al. 1991). Previous efforts at clarification and classification of periodontal disease and its agents using correct methods (by Clarke and Hirsch 1991a, Costa 1982, Hildebolt and Molnar 1991, and Hillson 2001) are still not universally acknowledged or utilized (as evidenced by Eshed et al. 2006, Sakashita et al. 1997, Yoshida et al. 2001, and others). Proper parameters for the assessment of oral health (including the use of accurate and up-to-date methods) require standardization before further advances can be made.

Aside from problems arising from misclassification there are difficulties even where this is not an issue. Extraction or other trauma-induced loss for example is unlikely to leave behind any trace on dry bone unless the alveolus, jaw, or tooth was fractured during the incident or process. Severe calculus accumulations are relatively common in a number of archaeological assemblages without the loss of the associated teeth and the relationship between the accumulations and periodontal disease and potentially pathological AMTL perhaps needs more thorough investigation. Furthermore, substantial continuous eruption is a problematic assignation unless the remaining neighboring teeth are themselves soon to shed.[2]

Despite such hindrances a thorough investigation into causes of tooth loss – and if it is possible to distinguish between them – presents obvious benefits. Recognition of the practice of ablation in past populations or the distinction between pathological responses may be discernible. All such study should be a combination of clinical and anthropological analyses and conjecture: a purely clinical approach is difficult for anthropological application; purely anthropological pursuit neglects recent developments in pathogenesis.

The following discussion is just that, a literary review for the purposes of osteological application which does not present any new data. The purpose of such review is primarily to assess what effect(s) the various impeti of tooth loss might have on the subsequent local healing (and specifically bone remodeling) process. An infection affecting the local bony tissues means the socket may heal very differently from non-pathological tooth loss (as occurs with physiological or non-invasive traumatic loss), just as a severely traumatic incident which also results in tooth loss (such as compound jaw fracture) presents more complex circumstances. Although firm identification of the cause of tooth loss is only rarely feasible at the present time, future research will hopefully continue to investigate these relationships and be able to somewhat remedy this shortcoming. For the time being

[2] The debate continues as to whether continuous eruption is (1) an independent age-linked occurrence or a response to (2) non-eroding mechanical factors or (3) dental erosion, but it seems to be an amalgamation of these (Ainamo 1978; Danenberg et al. 1991; Lavelle 1973). Because the actual mechanism is unknown however severe attrition (such as for loose teeth or poorly preserved alveoli) alone may not be an indicator for continuous eruption.

this inquiry is meant to instigate a consideration of the many influential factors inherent in the study of tooth loss and subsequent alveolar remodeling.

*Periodontal disease*

Periodontal disease is the leading reason for tooth extraction in modern western populations (Cahen et al. 1985; Morita et al. 1994; Stephens et al. 1991). But how prevalent was it in past peoples? It is frequently assessed by means of an increase in the distance between the cemento-enamel junction and the alveolar crest, where an increase in this distance (in most studies more than 2 mm) is interpreted as indicative of periodontal disease (Eshed et al. 2006; Molnar and Molnar 1985; Power 1985). Unfortunately this is far more likely to indicate hypereruption rather than alveolar erosion: such studies rarely take other alveolar changes (such as periostitis or porosity) into consideration, and findings are always age-linked – as is continuous eruption due to its accumulative nature (Ainamo 1978; Levers and Darling 1983). The recognition of this method as erroneous has thrown doubt onto previously calculated prevalences of periodontal disease in the past, what exactly is being classified as periodontal disease, and how different types of periodontal disease cause tooth loss (Hildebolt and Molnar 1991).

For the purposes of anthropology, periodontal disease encompasses gingivitis, periodontitis, and alveolar osteomyelitis.[3] Gingivitis is the infection and inflammation of gingival tissues (gums) and only affects this soft tissue: the bone beneath neither reacts nor becomes infected (Pihlstrom et al. 2005). In addition gingivitis may contribute to periodontitis but its development can easily occur without such a precursor (Clarke and

[3] Clinical definitions are more specific in their diagnoses of what appears as alveolar osteomyelitis, distinguishing between granulomas, cysts, and abscesses and various subgroups thereof (Carranza and Camargo 2006; Nair et al. 1996).

Hirsch 1991a; Pihlstrom et al. 2005). Earlier understanding was that not only was periodontitis the sequel to gingivitis, it was reasonably uniform and of a steady progression; more recent developments however have concluded that progression is instead in bursts of activity which occur randomly throughout the periodontal tissues, and that gingivitis is only involved as an agent of exposure rather than as an early, milder condition (Clarke and Hirsch 1991a; Clarke et al. 1986; Pihlstrom et al. 2005; Socransky et al. 1984). Supereruption can result in similar exposure and developmental defects affecting the cementum shell (in approximately 15-20% of teeth) can also permit bacterial penetration of the dentin and/or alveolus (Clarke and Hirsch 1991a).

Tooth loss resulting from periodontal disease is either due to the significant loss of bony support, the destruction of the periodontal ligament, or the destruction of the tooth root, although it is frequently caused by a combination of these (Hillson 2001). Although often grouped as "periodontal disease" by similar sequelae (inflammation, destruction of the periodontal ligament and support bone, and eventually tooth loss), alveolar osteomyelitis is initiated by bacterial invasion of the internal alveolus (usually via the tooth pulp) rather than from the alveolar surface as in periodontitis (Clarke and Hirsch 1991a; Hildebolt and Molnar 1991; Socransky et al. 1984). (As such the appearance of the alveolus following recent tooth loss should permit the identification of either osteomyelitis or periodontitis: destruction to deeper tissues or resulting in cloaca is indicative of the former, whereas the latter is characterized by a periostitial reaction of the external alveolus, specifically the crest.) The pulp cavity of the tooth then serves as a pathway directly into the bone which, without an artificial filling or tooth loss or removal, will not close. With simple periodontitis there is a chance of the alveolus healing following eradication of the infection, but an infected tooth will not alter its internal structure and so once there is a direct conduit between the gross oral cavity and the internal alveolus even the eradication of the initial infection will not prevent future infections.

*Continuous eruption*

Continuous eruption (also known as hyper- or supereruption) is a physiological mechanism to maintain efficient mastication as regular occlusal attrition increases. This ensures that the occlusal plane is kept both flat and at the same level respective to facial structures in order to insulate masticatory muscles and joints from excessive atypical tension (as illustrated in Figure 2.1.1). Where the occlusal plane is not kept relatively fixed in relation to these structures there can be insufficient stability to sustain normal masticatory forces and muscle strain, exacerbated atypical attrition, and tooth dislocation can occur (Clarke and Hirsch 1991b; Kaifu 2000).[4] In addition continuous eruption helps keep a disease-prevention system in working order: attrition helps keep caries initiation in check, the creation of secondary dentin keeps attrition from exposing the pulp cavity too swiftly and leading to pulpitis, and continuous eruption ensures mastication and calculus accumulations stay well above the gingival crest to avoid periodontitis.

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[4] Dislocation is more of a risk where normal weight-bearing structures, usually the buccal alveolar wall, are breached are destroyed as is not uncommon with large apical abscesses (Clarke and Hirsch 1991b).

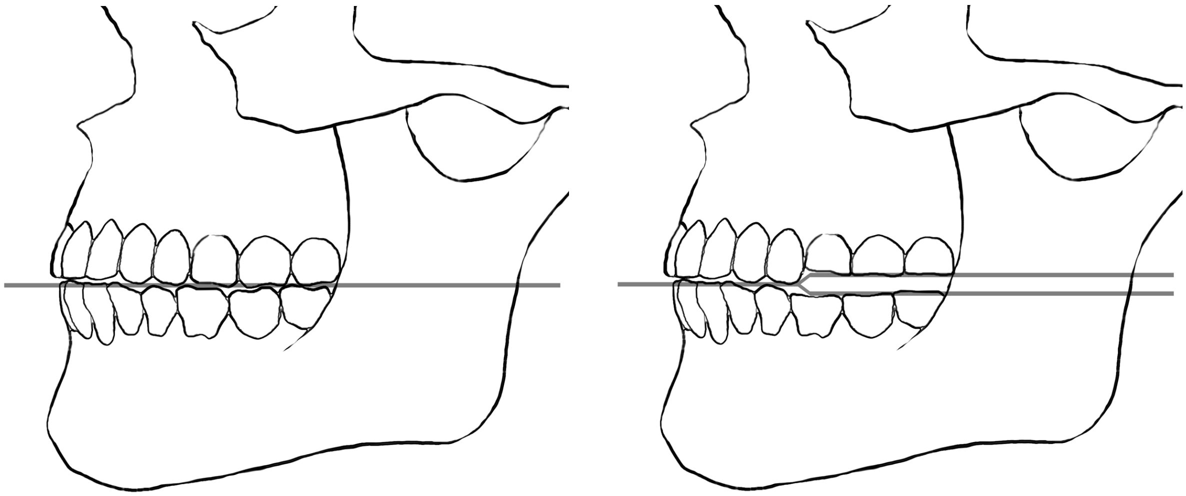

**Figure 2.1.1 Normal and Malaligned Occlusal Planes**
The left image is the most efficient and what occurs with either no occlusal attrition or effective compensation for attrition by continuous eruption. The right illustrates what would happen if a group of teeth (in this case the molars) was worn more rapidly than its neighbors (as is common in various populations depending on diet) without a compensatory mechanism. This situation would likely result in atypical occluso-posterior wear on the second premolars and may contribute to excessive mesial drift and temporomandibular joint disorder. The absence of such cases in the archaeological record is further evidence in support of continuous eruption.

Of greater relevance to studies of AMTL however are cases of extreme continuous eruption which lead not to dislocation but rather tooth loss. Although it can occur in healthy dentitions continuous eruption is more often a minor contributing factor to attachment loss largely created by pathological factors and resulting in tooth shedding (Clarke and Hirsch 1991b; Hillson 2001). Unfortunately the degree of supereruption required before non-pathological tooth shedding occurs or even how much is normal for many populations is unknown. Attempts to understand and quantify the occurrence and degree of continuous eruption in archaeological remains have been undertaken through the utilization of the distance between the cemento-enamel junction and alveolar crest (which has inherent flaws, see above) or the distance between a gingival crest estimated from supragingival calculus borders and either the alveolar crest, occlusal surface, or inferior alveolar canal (Glass 1991; Levers and Darling 1983). Further studies also argue about the severity of (age-linked) continuous eruption with regard to an age-linked increase in facial bone height (Ainamo 1978; Levers and Darling 1983; Whittaker et al. 1990). Although it is a physiological phenomenon it is unknown whether the sometimes significant population variation is due to genetic predisposition or dietary reliance; in addition the age-linked nature of continuous eruption may be ascribed either to it being an accumulative process (supererupted teeth do not stop being supererupted but may simply erupt further) or being responsive to attritional wear (which is also accumulative) (Lavelle 1973). Until the phenomenon is better understood these questions are also relevant in cases where continuous eruption causes or otherwise affects AMTL.

*Trauma (avulsion)*

Trauma is here defined as unintentional traumatic tooth loss or avulsion; traumatic tooth loss with the intention of tooth removal is designated ablation (below). Tooth loss due to trauma can occur either with or without damage to surrounding bony structures, and often with only minimal damage to soft tissues (Martins et al. 2004; Wright et al. 2007). In modern societies it is frequently studied amongst children where it often occurs during falls or play but it is also common amongst enthusiasts and professionals in various sports such as equestrianism, wrestling, and basketball (Adekoya-Sofowora et al. 2008; Kumamoto et al. 1997; Lukacs 2007; Martins et al. 2006). Of course it is also a common occurrence in incidents of interpersonal physical aggression and in cases of cranial trauma from car accidents (Birgen et al. 1999). Usually avulsion occurs through the exertion of a considerable force against the lingual/buccal crown of the tooth but without tooth fracture or fragmentation; trauma to the alveolar crest or jaws may also cause tooth loss (Birgen et al. 1999; Lukacs 2007; Saito et al. 2009). The anterior dentition and, of these, the maxillary central incisors are the most commonly affected due to root placement, orientation, and length as well as size and location of the crowns (Lukacs 2007). Although rates vary even amongst modern populations, and only rarely are rates known or published for the permanent dentition, prevalence can be assumed to be in most cases somewhere between less than 1% to 6% of individuals or less than 10% of teeth in either deciduous or permanent dentitions (Al-Majed et al. 2001; Hargreaves et al. 1999; Rodríguez 2007).

*Intentional removal (ablation)*

Tooth loss through behavior(s) with the intention of directly causing tooth loss, i.e. not that for which tooth loss is an accidental side-effect (such as a high-sucrose diet or hazardous contact sports), is separated from unintentional traumatic tooth loss. It also varies wildly between societies and is, was, or is suspected to have been performed for the purposes of punishment (Hrdlička 1940), as treatment for both oral and non-oral disease (Anderson 2004; Atkinson 2002; Graham et al. 2000; Pindborg 1969), as part of group initiation or as an identifier (Flood 2006; Han and Nakahashi 1996; Hassanali and Amwayi 1993; Pardoe 1995), as part of rite of passage traditions (Flood 2006; Han and Nakahashi 1996; Sangvichien 1966), in mourning (Pietrusewsky and Douglas 1993), and for cosmetic or orthodontic reasons (Becker 2000, 2003; Caldas 2000; Reich and Hiller 1993). Patterns vary both between and within societies depending upon motive and method but anterior tooth loss patterns without evidence of associated trauma or disease are often used (where strong ethnographic and/or historical corroboration are not available) to infer ablation (Hrdlička 1940; Kusaka et al. 2008; Pietrusewsky and Douglas 1993; others). Unfortunately this method has two major flaws: (1) posterior teeth are not taken into consideration and (2) trauma causing tooth loss can be either intentional or unintentional.

These flaws may be addressed separately: as regards the first, that of intentional posterior tooth ablation, modern western society provides an excellent example. Permanent premolars are not infrequently extracted in a clinical setting in order to provide additional space while maintaining the expected façade (incisors and canines). Third molars too are only rarely fully erupted and retained, instead usually extracted before or during eruption, even where they are favorably aligned, to prevent excessive mesial drift or a lengthy period of eruption (Lewis 1980). Although modern orthodontistry may argue these are prophylactic measures to maintain good oral health, physiologically mesial drift, crowding, and third molar eruption (despite usually being lengthy and frequently unpredictable) are not necessarily associated with poor oral health. Modern western society views straight, even, white teeth as attractive as evidenced by the plethora of tooth-whitening products available and the high prevalence of orthodontics including braces, head gear, and retainers. Although severe malocclusion may interfere with mastication, a considerable portion of both preventive and corrective orthodontistry is largely cosmetic.

As to the second failing: tooth removal is a form of trauma. Tissues are damaged, nerves and blood vessels severed, and sometimes bone or tooth is fractured. The degree of trauma is dependent on the method and complications, and as recorded methods vary from severe extraoral force to break the tooth to gentler luxation and extraction, speculation in populations without such records must encompass this broad spectrum (Flood 2006; Graham et al. 2007; Klokkevold 2006; Pietrusewsky and Douglas 1993). As the division between tooth loss from trauma (see above) and that from ablation lies in intent, once traumatic tooth loss is identified the question becomes: how is intent identified from the skeletal record?

But first the cause of tooth loss must be determined to have been from trauma and not disease or supereruption. Indicators of traumatic tooth loss in vivo include: retained tooth fragments; alveolar or jaw fracture; a high AMTL rate coupled with low caries prevalence, a low degree of calculus accumulation, and regular attrition which does not penetrate pulp cavities; and, in some cases, a greater variation of AMTL rates between subgroups within a population than are readily attributable to variance of diet- or behavior-linked dental disease[5] (Pietrusewsky and Douglas 1993; Robb 1997). Other authors have included additional criteria within this list which, although allowing for easier and possibly more reliable skeletal identification, are not necessarily upheld by ethnographic comparisons; most common among these are an identifiable pattern (the visible anterior dentition are focused on in particular) and the absence of dental disease (Hrdlička 1940; Pietrusewsky and Douglas 1993; Robb 1997). It is here that the question of motive becomes significant: where dental diastema serves to identify a member of a group (ranging from achievement of adulthood, a person in mourning, or member of a certain community) or is seen as aesthetically pleasing then the focus on anterior dentition is reasonable.[6] Where tooth loss is intended for reasons which do not require continuous visible evidence (as in disease treatment, orthodontics, or punishment) however the posterior dentition may be similarly affected.

Although it is tempting to derive a series of specific classification criteria useful for the identification of ablation in past societies, the variation even within a single population is such that this is not feasible. Instead more generalized criteria, such as lack of evidence of

[5] This final point relies on apparent differences between groups such as males and females, or higher and lower status, or family groups, which may not necessarily exist in all populations.

[6] Note that this does not take the incident of ablation into consideration, only the presence of the diastema itself, which is not necessarily intended to indicate group membership but rather that the *process* of (presumably painful) tooth loss was undergone, thus placing the individual within a certain group.

congenital absence, low rates of pulp-cavity-penetrative caries or -exposing attrition, low incidence of severe attachment loss, and particular patterns within not just an individual but within a given population or population subgroup may be indicative of tooth ablation. In addition the incidence of certain sequelae – retained tooth roots or alveolar fracture for example – may be common where tooth removal took place with certain methods. In large part most identification of prehistoric populations which practiced ablation is largely conjecture but this does not mean it is entirely without merit; rather than definitively asserting that ablation occurred in a given individual or population in many cases it should at least be considered as a possibility and conclusions derived accordingly.

*Other causes*

In addition to these oral causes of AMTL there are two additional systemic causes which bear mentioning. One, leprosy, is affiliated with AMTL through rhinomaxillary syndrome which induces rapid bony resorption of this region and affects the alveolus for the anterior maxillary dentition (Roberts and Manchester 2005). Secondary infection further exacerbates and may accelerate the process (Roberts and Manchester 2005). The other, scurvy, is historically notorious for causing tooth loss; in a non-pathological environment however teeth are incredibly unlikely to be shed solely due to scorbutic oral changes (Aufderheide and Rodríguez-Martín 1998; Leggott et al. 1991). Instead the significant attachment loss due to lack of formation of periodontal ligament fibers coupled with secondary periodontal infection and alveolar crestal resorption are responsible for the associated tooth loss (Aufderheide and Rodríguez-Martín 1998; Hunt and Paynter 1959; Leggott et al. 1991). Regardless of whether tooth loss occurs as a result of primary or secondary scorbutic changes however it is not uncommon to find elevated rates of AMTL in populations with a high prevalence of scurvy, particularly for the anterior dentition (Boston et al. 2008; Roberts and Manchester 2005). Both scurvy and leprosy are discussed in more detail below as inhibitors/accelerators of bone and specifically alveolar remodeling activity.

## 2.2 Socket Healing Process

The rate of bone remodeling in the alveolus, as in other locations throughout the system, varies dependent upon a wide range of interference from vitamin, mineral, pharmacological, pathological, and physiological factors as well as mechanical stresses, local and systemic health, and size of the socket or defect. The uninterrupted process however has been intensively studied and a population-, age-, and sex-independent process has been identified. Although there is variation dependent on these factors (and others such as site or number of teeth extracted) this is only in duration, not pattern of progression. The point at which a socket is determined "healed" is difficult to identify: relevant studies are usually truncated by arbitrary end dates, leaving the details of long-term healing and post-healing dynamics unknown. For the most part sockets are deemed healed once (a) they are completely filled with an internal structure indistinguishable from the surrounding alveolus in terms of vascularization and composition of trabecular bone; (b) epithelization is complete; and (c) external crestal woven bone has been completely replaced by lamellar bone. The length of time required for this end-stage to be achieved however is cause for debate and seems to require more than six months (Schropp et al. 2003; Trombelli et al. 2008). Difficulties were experienced in attempts to apply the results from a plethora of largely histological studies to macroscopically observed dry bone specimens but a reliance on the published radiographic data and studies of alveolar remodeling in general minimized this problem.

*Histology and radiography*

Clinical studies are generally largely concerned with damage to and complications of soft tissues with regard to disease prevention and treatment and patient comfort; several exceptions occur however particularly where the intended application is in implantology where factors like bone function, remodeling, and stability are crucial. Issues such as residual ridge resorption and post-healing ridge activity are also key points in most long-term clinical trials but these have little bearing on the present study (Araújo and Lindhe 2005; Nishimura et al. 1987). Often these studies are performed on animal models where the subjects can be sacrificed in order to obtain complete histology sections.

Although the results of histological studies are perhaps those most frequently applied due to the detail provided, more general information is also produced: the most relevant indicates that blood clots within the first five days, bone forms from days 5 to 20, and then remodels from days 20 to 60 (Elsubeihi and Heersche 2004). The more precise healing process however is far more elaborate: blood clots within a day, vascularizes, and then is broken down within the first week by granulation tissues (Adeyemo et al. 2006; Amler 1981; Cardaropoli et al. 2003; Pietrokovski and Massler 1967). Bundle bone – largely composed of tightly bound collagen fibers in the periodontium – is rapidly resorbed within two weeks post-extraction to be replaced by woven bone; this can considerably thin the buccal and lingual alveolar walls which can be problematic where implants are planned (Araújo and Lindhe 2005; Cardaropoli et al. 2003). At this time osseous resorption occurs through the activities of osteocytes, osteoclasts, and even macrophages and monocytes and appears to be largely if not solely mechanistic so that an increase in pressure increases resorption (Hammarström and Lindskog 1985). Thus the lack of pressure due to a now-absent tooth is responsible for considerable new bone formation. From approximately two weeks to a month after extraction woven bone largely lines the internal socket (originating at the apex) and fibrous connective and pre-osseous tissues replace the granulated tissues (Adeyemo et al. 2006; Amler 1981; Araújo and Lindhe 2005; Cardaropoli et al. 2003). From this point until total socket ossification woven bone is slowly replaced by lamellar bone which internally remodels to form marrow and trabecular bone; this process is far lengthier than the earlier stages of healing and may still not be concluded up to three months post-extraction (Cardaropoli et al. 2003; Elsubeihi and Heersche 2004; Trombelli et al. 2008).

Variation between studies is clear and likely population-linked. Some assert the presence of woven bone bridging near the crest which then serves as a stable structure for mucosal epithelization and later a cortical crest (Cardaropoli et al. 2003; Pietrokovski and Massler 1967). Others have had various results also where one or several neighboring teeth were extracted or if the tooth was maxillary or mandibular, an incisor or molar. For the most part there is a general consensus that the healing process is delayed for incisors, maxillary teeth, and where multiple neighboring teeth are extracted versus their aforementioned respective counterparts (Elsubeihi and Heersche 2004; Grewe and Felts 1969; Pietrokovski and Massler 1967).

Radiography has also been utilized, albeit far less frequently than histology and with mixed results, to track post-extraction healing with a focus on osseous development. In one study radiographic imaging was determined to be ineffective beyond a certain point as the inner lining of the sockets consisted of radiopaque tissue, making the sockets appear uniform to the surrounding alveolus only 60 days post-extraction (Elsubeihi and Heersche 2004). In a previous publication however where radiography was the sole method this was not observed and instead it was possible to precisely map osseous activity with subtraction radiography (Schropp et al. 2003). Perhaps the most novel results from this earlier study were that resorption occurs primarily, for both vertical and lateral osseous activity, in the first three months following extraction and modeling from the third to twelfth months (Schropp et al. 2003). Difference between socket locations were not apparent and the mature bone filling the socket at the end of the study (one year post-extraction) did not extend to the level of either the mesial or distal interdental ridges, instead leaving a permanent depression at the site of the former socket (Schropp et al. 2003).

*Osteology*

Studies assessing alveolar remodeling in dry bone have not been published. What is however recorded as a matter of course in basic osteoarchaeological analysis is whether or not a tooth was lost antemortem as determined by a remodeling or remodeled socket. Although extensive efforts to classify and interpret periodontal disease and caries prevalences and patterns based on their detailed appearances in dry bone have been encouraged in various publications, this same attention has not been paid to the subject of AMTL (Clarke et al. 1986; Hildebolt and Molnar 1991; Hillson 2001; Lukacs and Largaespada 2006; Nelson et al. 1999; Tal 1985; many others). Unfortunately this means that only limited retrospective application of results from the following or similar research would be possible. For this reason in particular general dental inventories would benefit from including a rough stage of remodeling achieved (i.e. half-filled, completely remodeled, etc.) at the time of death. Such a concession would then make retrospective analysis – particularly in cases where the remains were reburied, destroyed, or are otherwise inaccessible – at least a possibility.

There is a similar lack of specialist studies of alveolar remodeling not directly related to tooth loss or oral defects but the plethora of publications on general bone remodeling presents a vast amount of information regarding hard tissue dynamics, particularly with regard to sex, age, and loading (Carter 1984; Chamay and Tschantz 1972; Martin 2000; Mays 2000; Stout and Lueck 1995; Wolff 1986; many others). Simply put, osseous remodeling consists of the breakdown and resorption of old bone by osteoclasts and osteocytes and creation of new bone by osteoblasts and resorbed by osteoclasts (Amenta and Amenta 1997; Ott 2002). Although various factors have differing effects the greatest influence is by the forces exerted on the local bone at muscle insertions (tensile) and, to a lesser extent, simple gravity and the weight of the body or element (compressive) (Chamay and Tschantz 1972; Wolff 1986). An increase in either of these forces can rapidly increase bone modeling and rate of remodeling just as a decrease can increase bone resorption and decrease the rate of remodeling (Carter 1984).

With this in mind it is possible to infer that mechanical forces in particular are extremely likely to have a significant bearing on alveolar remodeling as it does on initial alveolar formation (Shimomoto et al. 2007). Because these forces may vary considerably from those subjected upon many other skeletal elements however, the remodeling rate is expected to vary from that of, for example, the anterior femoral shaft or, to an even greater degree, non-load-bearing elements (Ericksen 1976). The alveolus serves as a buffer for the linear and torsional forces exerted on the teeth from multiple directions and is also subject to negative strain from muscles which insert there or at its borders.[7] Due to the combination of forces exerted on the alveoli indicators of tensile stress at remodeling sites can be inferred from site location and those of intermittent compression stress may be inferred from neighboring tooth status: variation in rate of socket healing due to either or both of these factors may be linked to these mechanics.

## 2.3 Inhibitors and Accelerators of Bone Activity

As a local process within a larger system, bone remodeling in the alveolus is affected by the presence and absence of a number of systemic vitamins, minerals, medications, and pathologies (outlined in Table 2.3.1) in addition to local considerations such as alveolar defects. Although the myriad medications in use today which affect bone activity as either a primary or secondary effect are not of concern for archaeological populations, scurvy, anemia, and even fluorosis are both prevalent and apparent throughout osteological assemblages and modern populations. As such their estimated impact upon bone remodeling (and alveolar remodeling in particular) may be at best nonexistent, negligible, or controllable in individuals with indications of such conditions. For the purposes of the application of any results obtained from this project to past peoples, those processes which

[7] Most notable is the buccinator but other smaller muscles also just border the alveolus: the depressor septi nasi, mentalis, platysma, mylohyoid, and geniohyoid. Most of the muscles controlling mastication and lower facial expression insert into the soft tissues around the mouth rather than into or around the alveolus.

**Table 2.3.1 Common Accelerators and Inhibitors of Bone Activity**

| **Factor** | **Effects on bone** |
|---|---|
| Menarche | Rapid systemic increase in remodeling and formation which gradually decreases in teen years |
| Menopause (female) | Decreased remodeling; pre- and peri-menopausal initial gradual decrease in formation and increase in resorption is followed by a rapid post-menopausal drop in formation and drastic increase in resorption, resulting in osteopenia and osteoporosis |
| Menopause (male) | Decreased remodeling; gradual long-term decrease in formation and increase in resorption resulting in eventual osteopenia and possible osteoporosis |
| Osteopenia/osteoporosis | Rate of bone resorption exceeds rate of formation |
| Vitamin D deficiency (rickets/osteomalacia) | Insufficient mineralization results in poor calcium absorption, eventually resulting in osteopenia and osteoporosis |
| Calcium deficiency | Increased resorption and decreased formation and rate of remodeling, eventually resulting in osteopenia and osteoporosis |
| Vitamin C deficiency/scurvy | Encourages resorption and discourages ossification, delayed wound healing and tissue formation |
| Vitamin C surplus/hypercitricemia | Lack of osteoblastic activity |
| Boron deficiency | Inhibits osteoblastic activity and vascularization |
| Iron deficiency (anemia) | Decrease in osteoblastic activity |
| Iron surplus (polycythemia) | Increase in osteoblastic activity |
| Fluoride (low dose) | Increases formation of trabecular bone, decreases alveolar resorption |
| Fluoride (high dose)/fluorosis | Calcification of soft tissues, osteosclerosis or osteoporosis |
| Leprosy | Rapid rhinomaxillary resorption and remodeling, inflammation |
| General oral periostitial pathology (i.e. sinusitis) | Increased localized resorption and remodeling, inflammation |
| Local oral pathology – periostitis | Increased localized alveolar resorption, remodeling, and inflammation |
| Local oral pathology – alveolar osteomyelitis | Localized alveolar destruction, rapid resorption and remodeling, inflammation |
| Diabetes | Progressive bone loss and impaired wound healing |
| Chlorhexidine | Inhibits bony resorption |
| Calcitonin | Inhibits bony resorption and remodeling by limiting osteoclastic activity |
| Bisphosphonates | Inhibit bony resorption and remodeling by limiting osteoclastic activity |
| Parathyroid hormone | Stimulates bone formation by encouraging osteoblastic activity |
| Estrogen (as hormone replacement therapy) and selective estrogen receptor modulators | Inhibits bony resorption, delays osteopenia/osteoporosis |

Common vitamin, mineral, physiological, pathological, and pharmacological factors which interfere with normal bone modeling, remodeling, and resorption.

affect bone remodeling are analyzed in detail regarding their potential for interference in alveolar bone modeling. Modern pharmacological interventions are also examined in order to identify whether or not subjects in the clinical phase of the project should be screened and rejected on the basis of their use.

*Vitamin and mineral*

Many vitamin and mineral deficiencies and surpluses are more often categorized only by their pathological, extreme forms. An insufficiency of vitamin C is better known as scurvy, one of iron as anemia; these conditions however are largely dietary[8] rather than being infectious, neoplastic, trauma-induced, or degenerative, and so they have been categorized separately from those pathological and age-related physiological changes which also affect bone activity. Calcium and vitamin D deficiencies however, although caused by malnutrition, are also strongly related to post-menopausal degenerative changes and so will be discussed along with other effects of menopause – like osteopenia and osteoporosis – below. In an attempt to identify the normal progression of bony socket healing dietary factors which either accelerate or inhibit this process have been investigated; those deficiencies which have less significant effects specifically on bone resorption, remodeling, or modeling have been omitted from this discussion.

Perhaps of the most questionable influence is fluoride, particularly in older studies and in large part likely due to intense scientific and public dissent regarding fluoridation of public drinking water in some countries (Ripa 1993). Studies have shown that, for the most part, low doses of fluoride have been found to encourage bone formation, particularly of

[8] This is of course not always true. Anemia in adults is more commonly trauma-induced for example, and osteoporosis is an unusual situation where both dietary calcium insufficiency and age-related physiological degradation play important roles (Stuart-Macadam 1998).

trabecular bone, and significantly reduce periodontal alveolar resorption; higher doses may be linked to a decrease in osteoblastic activity (Ericsson and Ekberg 1975; Kristoffersen et al. 1970; Lafage et al. 1995; Leonard et al. 1980; Messer et al. 1983). Fluorosis however, most often resultant from long-term excess fluoride in drinking water or air pollutants, can cause the calcification of fibrous tissues, affect bone chemistry similarly to both osteoporosis and osteosclerosis, and generally be composed of hyperactive osteoblastic properties (Krishnamachari 1986). Regardless of whether low doses of fluoride (i.e., too low to cause apparent fluorosis) legitimately plays a significant role in alveolar remodeling, it is unfortunately not a controllable factor for the present study. Modern samples will be obtained from a dental clinic where patients are very likely to regularly brush their teeth with a toothpaste containing fluoride, and the archaeological assemblages substantially predate the 20th century introduction of fluoridated toothpaste and are not from an area with high levels of groundwater fluoridation. Fluoride is simply not something which can be reliably controlled for when bridging the gap between living western and past populations.

Also of interest are the quite recent preliminary investigations into links between boron deficiency and osteochondrosis in veterinary medicine in large mammals, particularly as osteochondroses are more usually correlated to trauma in archaeological samples (Avenatti 2009). Although osteochondrosis is generally of very little interest to dental anthropology, artificial boron deficiency in a recent study resulted in significantly decreased numbers of osteoblasts following tooth extraction and thus inhibited bone formation at the socket site (Gorustovich et al. 2008). Unfortunately a lack of extensive literature on the subject of boron deficiency in humans leaves many unanswered questions.

Iron and vitamin C have unique positions of producing distinct effects both in deficient and surplus quantities. Anemia has been associated with a decrease in bone formation and polycythemia with an increase specifically in the alveolus through respective inhibition and excess of oxygen transfer (Gorustovich et al. 2006). Scurvy produces nonhydroxylated collagen which in turn results in delayed wound healing of soft and hard tissues; of particular relevance is the prevention of ossification of fibrous tissues without which socket healing stagnates (Bsoul and Terezhalmy 2004). Bone is simultaneously not created and that which is already present is rapidly resorbed (Hunt and Paynter 1959). Hypercitricemia is, curiously, associated with similar effects as the fibers of the periodontal ligament are degraded and osteoblastic activity rapidly decreases (Tsunemitsu et al. 1963).

*Physiological*

Puberty in males and females is a period of rapid growth. In bone this is brought about by a systemic increase in rate of remodeling in addition to increased new bone formation and decreased resorption (Cadogan et al. 1998; Eastell 2005; Stout and Lueck 1995). Although puberty is often ascribed a discrete chronological age, particularly with women where it is derived from age at menarche, skeletally it is a process with a peak and gradual tapering to normal adult bone activity dynamics; this is usually achieved within five years of menarche in females and by age twenty in both sexes (Cadogan et al. 1998; Eastell 2005; Stout and Lueck 1995). Age at peak skeletal puberty varies between the sexes (with males reaching this point some one to two years after females), between races, and based on a variety of additional criteria from socioeconomic status to altitude (Aw and Tye 1970; Jones et al. 2009). Until recently age at menarche – and related age at systemic pubertal growth peak – has steadily decreased worldwide at the rate of approximately one year every fifty years, although this may be explained through method of data collection (Jones et al. 2009; Kalichman et al. 2006; Tryggvadóttir et al. 1994; Żarów and Cichocka 2008). Atypical retardation of menarche occurs particularly during periods of intense personal stress (such as that during socio-political upheaval, war, or due to a death in the family) or due to physical stress from mal- or undernutrition or prolonged illness (Garnier et al. 2005; Kalichman et al. 2006; Prebeg and Bralić 2000; Simondon et al. 1997). Current ages at menarche in stable western populations have tended to cluster around 13 to 15 years since the 1970s; in past populations it may have occurred a few years later but still likely prior to 20 (Cameron et al. 1991; Magnússon 1978; Shakir 1971; Stout and Lueck 1995).[9]

Menopause is both a male and female phenomenon; in females it is usually far more physically and mentally significant and officially occurs one year after the cessation of the last menses, after which time estrogen is produced only in very trace amounts (Gosden 2007; McKinlay et al. 1992; Reynolds and Obermeyer 2005). This usually occurs at or shortly after the age of 50 in women but depends on numerous factors such as family history, stress, socioeconomic status, and race: Beyene and Martin (2001) for example report native Mayan women experience menopause at an average of 44 years of age (Gold et al. 2001; McKinlay et al. 1992; Reynolds and Obermeyer 2005). In males it is linked to a decrease in testosterone and is known as andropause, ADAM, and by various other names; it is far more gradual than the female form and usually begins from age 50 to 60

9 Note that although there is a distinct absence of similar data regarding male growth rates, it is a reasonable assumption that their growth and pubertal peaks, although later than those of females, are affected similarly by physical or psychological stresses. In addition, if the gradual decrease in age at menarche over the past century or so is related to factors which also affect males (such as environment, diet, etc.) then it may also be reasonably assumed that their pubertal processes and peaks have been similarly gradually accelerated with respect to chronological age.

and continues until death (Matsumoto 2002; Morales et al. 2000; Vermeulen 2000). Both males and females experience the decreased bone density due to decreased remodeling and osteoblastic activity and increased trabecular and cortical resorption characteristic of age-linked osteopenia and osteoporosis although it occurs earlier and more severely in females (Stini et al. 1992). Changes in diet and lifestyle, particularly those which effect a decrease in calcium absorption and vitamin D synthesis, may also contribute to these effects and deficiencies in either regard can induce non-age-related osteopenia or osteoporosis (Lerner 2006b; Roberts and Manchester 2005). Conclusions of osteoporosis prevalence in past populations have at times conflicted but largely with good reason: like other degenerative diseases osteoporosis has become a problem for modern populations due to substantially increased longevity than past populations; it is less a question of whether or not osteoporosis occurred in past populations and more a question of whether individuals lived long enough to be affected by it (Ericksen 1976; Mays 2000). Some such effects, such as fractures (particularly of the femoral neck) are more obvious than others, such as an increase in periodontal resorption and tooth loss (Binte Anwar et al. 2007; Gronholz 2008).

*Pathological*

Although a great many systemic diseases and medical conditions as varied as HIV/AIDS and Down's syndrome have oral manifestations, most of these affect only of the soft tissue (Pihlstrom et al. 2005). Diabetes however is known to contribute to not only plaque formation and an increased caries rate but also to alveolar resorption and impaired wound healing of both soft and hard tissues (Garcia et al. 2001; Pihlstrom et al. 2005). Leprosy, although the severity of the disease required to develop rhinomaxillary syndrome is rare now in the western world, is well-known in past populations for the rapid resorption and remodeling of the anterior maxillary dentition; this characteristic has however also manifested occasionally with tuberculosis and, rarely, treponemal disease in archaeological samples (Roberts and Manchester 2005).

In addition to systemic diseases and disorders which affect the alveolus there are also local conditions which may interfere. Significant palatally-localized sinus-origin infection can induce local oral pathological responses including resorption, increased rate of remodeling, and general inflammation of the soft and hard tissues (Roberts and Manchester 2005). More common however is local periodontal disease from periodontitis to alveolar defects (Clarke and Hirsch 1991a; Hillson 2001; Socransky et al. 1984). Like other infections of either the internal or external bone there is bony resorption, increased remodeling, and, in the case of alveolar osteomyelitis, the formation of bony plaques at the borders of the abscess (Alt et al. 1998; Hillson 2001). These local pathological indicators are easy to identify and so are less easy to overlook than more subtle responses to systemic disease.

*Pharmacological*

Most medications which strongly affect bone dynamics do so in a way which encourages bone growth and are utilized to prevent or treat osteoporosis; others however affect bone activity as a side effect such as lithium and heparin (Gronholz 2008). Those pharmaceuticals which are commonly prescribed for osteopenia or osteoporosis may require anywhere between six months to five years before actuating positive results; this indicates their influence is gradual and long-term (Gronholz 2008). For these purposes bisphosphonates (alendronate, ibandronate, risedronate, and zoledronate) and the amino-acid calcitonin are the most commonly employed; the former slows the entire remodeling process but calcitonin accelerates this rate (Altundal and Güvener 2004; Gronholz 2008; Hunziker et al. 2000; Lafage et al. 1995; Ubios et al. 1991). Both work to inhibit bony resorption through limiting osteoclastic activity and produce the best results in bone density recovery when used in tandem with an osteoblastic-stimulating medication such as parathyroid hormone (Altundal and Güvener 2004; Gronholz 2008; Lafage et al. 1995). Parathyroid hormone, an anabolic steroid, requires careful dosing: pathological hyperparathyroidism (which may be pharmaceutically induced) causes systemic bone resorption and reduces total bone density as well as cortical bone thickness (Garcia et al. 2001).

Estrogen replacement therapy slows resorption and remodeling similarly to bisphosphonates but is also frequently prescribed to treat other symptoms before and after menopause and is also commonly used as a birth control medication in fertile women (Hunziker et al. 2000; Lerner 2006b). Selective estrogen receptor modulators (Tamoxifen, Raloxifene) can provide both encouraging and inhibiting effects on bone dynamics through the manipulation of endocrine feedback systems; their influence can be similar to or more extreme than pre- or post-menopausal states (Gronholz 2008). Finally chlorhexidine, a common medical antiseptic (which is also frequently used in dental surgery and extractions), has been found to somewhat inhibit osteoclastic activity and so slow alveolar resorption (Leonard et al. 1980).

### 2.4 Clinical Tooth Extraction

Exodontia is a common feature of modern dentistry. Usually a simple procedure, it is frequently performed with the use of at least minimal local anesthesia and on all teeth, permanent and deciduous, fully erupted and impacted, for a variety of reasons including prevention of local disease, as an aspect of emergency trauma care, or as part of a long-term orthodontia plan. Methods vary depending on the tooth, the patient, and mitigating factors like eruption status and tooth integrity. The motivation behind considering this process as a case study is twofold: first, it represents the best documented practice of intentional tooth removal in any anthropological literature, with a variety of tools and techniques discussed at length in the literature. Second, phase 1 of the following project relies heavily on cases of modern dental extraction and so an understanding of this process – and how it may differ from cases of AMTL in archaeological samples – is beneficial to the project as a whole. That said, this is not meant to be a comprehensive study, as such investigations have already been performed and assembled into tomes by more qualified medical practitioners: instead it is only meant to provide an idea of the more common practices and in particular make it possible to infer the effects different circumstances have on socket healing.

*Reasons for extraction*

Of primary concern for dentists when forming treatment plans inclusive of exodontia is function. Teeth which are insecure due to periodontal disease or trauma, very mobile without reasonable methods for stabilization, or at risk of becoming insecure are good candidates for extraction (Carranza and Takei 2006; Klokkevold 2006). Orthodontics, when applied correctly, allow or encourage a level occlusal plane and a stable, functional dentition; exodontia in orthodontics is however often utilized for aesthetic purposes or as a matter of course (e.g. many third molar extractions) (Caldas 2000; Carranza and Takei 2006; Reich and Hiller 2006). These cases are nevertheless in the minority: in multiple studies from around the world from both socialized and private medical systems tooth extraction is most frequently a response to caries and periodontal disease, comprising more than half of all incidents (Cahen et al. 1985; Morita et al. 1994; Stephens et al. 1991; many others). Prosthodontics and orthodontics are usually the cause of some 5-15% of extractions with trauma representing less than 10% (Caldas 2000; Chestnutt et al. 2000; Reich and Hiller 2006). Failure of endodontics or other treatments may also sometimes require tooth extraction (Adeyemo et al. 2007; Chestnutt et al. 2000). The extraction of unstable teeth where the alveolus is or could become stable is occurring more frequently in order to take advantage of the benefits of implanted prosthodontics (Carranza and Takei 2006).

*Process and techniques*

Although a variety of methods are used depending on the requirements of the case at hand, the most common involves simple noninvasive extraction with forceps alone or in conjunction with penetrative luxation (Adeyemo et al. 2007; Klokkevold 2006). Such penetration, with a small, thin instrument, severs part or all of the periodontal ligament and elevates the tooth allowing for easy extraction; the size of the tool is limited largely by the size and shape of the socket (Klokkevold 2006). This method avoids incisions and in most cases can be performed quickly and with minimal hemorrhage; multi-rooted teeth however may be cut into appropriate pieces for removal (Klokkevold 2006). Impacted teeth require more invasive methods: third molars in particular are often extracted before or during eruption by making incisions in the crestal and buccal mucosa and buccal alveolus for the insertion of an elevator into the crypt (Lewis 1980; Praveen et al. 2007).

*Medications and treatments*

Immediately following extraction the socket is usually cleaned of soft tissue and rinsed with hydrogen peroxide or saline or other solution to sterilize the wound (Klokkevold 2006). The use of a collagen or nonresorbable membrane or bone transplant to pack the socket has been shown to significantly preserve ridge resorption and reduce healing time (Klokkevold 2006; Luz et al. 1999; Patino et al. 2002). Wound closure, either with sutures or sutures and a mucoperiosteal flap, has a similar effect (Klokkevold 2006). Paracetamol and NSAIDs are recommended to control postoperative pain and swelling and antibiotics may be prescribed to either treat an associated infection or prevent one from developing. Orthodontic appliances may now also be employed to either take advantage of the available space to alleviate crowding or to encourage the eruption of permanent dentition (Carranza and Takei 2006).

Use of implants is increasing drastically and where one or more is intended particular care must be taken to preserve or reconstruct the alveolar ridge either in the short- or long-term and insurance procedures such as bone transplants are becoming more common (Bartee 2001; Campbell 1998; Lee 2003). There exist several different kinds of implant, although the screw-type is most common, and the use of different types at different implant-to-crown frequencies varies dependent upon the specific case (Christensen 2002). Depending on the integrity of the alveolus implants are inserted immediately, approximately two months, or approximately four to six months following extraction although may not be inserted until several years later (Akça et al. 2000; Carranza and Takei 2006; Winkler 2000). Assurance of alveolar integrity however is not always easy to identify and so various preoperative methods of assessing site suitability for implant have been developed (Akdeniz et al. 2000; Flanagan 2000).

*Common complications*

Complications are diverse and often dependent upon details of extraction and peri- and post-operative treatments. Fractures of the tooth, alveolus, or neighboring teeth or dislocation of neighboring teeth are possible complications during extraction (Adeyemo et al. 2007; Amler 1999). Such complications in turn often result in a longer extraction time as well as damage to the soft tissue with prolonged excessive hemorrhage: these are significant risk factors in the subsequent formation of alveolar osteitis, inflammation, or infection (Adeyemo et al. 2007; Amler 1999). While any infection delays socket healing, osteitis, also known as dry socket, does so considerably and eventually results in putrefaction and necrosis (Adeyemo et al. 2007; Amler 1999). This serious complication is caused by an absence of blood clot and drastically inhibits the healing process (Adeyemo et al. 2007; Amler 1999). This is due to disruption in the conversion of the blood clot into granulation tissue and considerably delays ossification (Adeyemo et al. 2007; Amler 1999). It has been associated with longer extraction operation times and heavy bleeding during the operation (Adeyemo et al. 2007). Invasive operations such as the extraction of impacted third molars also have an increased risk of alveolar and lingual nerve damage (Amler 1999; Lewis 1980; Praveen et al. 2007). Implant-specific complications largely involve residual ridge resorption and an unstable site or postoperative infection which may necessitate removal of the implant (Hoexter 2002; Klokkevold 2006; Nishimura et al. 1987; Sussman 1998).

# CHAPTER 3 PHASE 1 MATERIALS AND METHODS

This first of two experimental phases has the primary purpose of estimating time since tooth loss (TSL) with stage of fullness. The data will be derived from dental radiographs of clinical patients. The study will be a retrospective one consisting of data collection from hard copy panoramic radiographs and patient files and then statistical investigation. Samples will be selected at random from several thousand cases in repository at a regional dental surgeon's practice and assessed with regard to their suitability. Individuals or specific remodeling sites will be excluded on the basis of practical considerations such as a lack of sufficient radiographs, unclear imaging, or overwhelming defects at the remodeling site as well as on criteria pertaining to bone dynamics such as certain conditions or medications. Data recorded for each individual consist of patient details (age, sex, a basic dental inventory), site-specific information on the remodeling site (location, date of tooth loss/extraction, related treatment), and subsequent follow-ups (TSL, fullness, complications and treatment). Radiographs will be utilized in order to assess stage of socket fullness at follow-ups; this stage will later be compared to TSL. Additional data which were initially intended to be studied in this phase, such as interdental ridge status, were not recorded due to the nature of panoramic radiographs.

The analysis of these data will utilize myriad statistical techniques in order to assess the data both mathematically and visually. Descriptive statistics will provide an initial understanding of the entire dataset and cluster analysis will group stages of fullness by TSL, indicating both the success or failure of the entire premise of the experiment with averages for each cluster providing base estimates for given stages of fullness. Additional variables will be assessed with ANOVA and linear models to see if their TSLs vary significantly within a given cluster. The average TSLs for each value of those variables which do exhibit significant variation will then be utilized in phase 2 of the experiment where they will be applied to archaeological remains.

With an awareness of its eventual application and the restrictions of archaeological material certain concessions have been made primarily in terms of grouping of samples by age and TSL. Instead of the high precision favored by most clinical trials individuals have been placed into one of three age groups (less than 20 years, 20 to 50 years, and greater than 50 years) to determine if the different bone dynamics during puberty and adulthood and after menopause have significant bearings on socket healing. The TSL for each follow-up has been calculated in weeks rather than days.

### 3.1 Imaging

The study will utilize panoramic radiographs previously obtained through assessments following trauma or prior to implant; unfortunately this also limits materials to a less than ideal imaging medium. Slight variation in tooth arch angles and cranial shape can be problematic for assessments of midline cross-sections parallel to the alveolus with panoramic radiographs (Pasler and Visser 2007; Whaites 2003). Although the literature review indicates that there is unlikely to be substantial variation in fullness between the lingual or buccal faces of a remodeling socket this is still a possibility and may be more likely in posterior sockets. Due to the nature of dental treatments performed at this particular practice – largely implant-related – it is expected that a reliable cross-section through the complete healing socket from apex to crest will be apparent for each film.

## 3.2 Sample Selection

Cases will be selected at random from the archives of [redacted], an oral surgeon with a specialty in trauma, orofacial plastic surgery, and implantology in Fulda, Germany. Those cases considered for the experiment will be limited to those patients who had been to the surgery at least once within the previous decade in order to insure regularity of recording, pharmaceutical and physical treatment and methods, and standardized images. Many of the patients are elderly and seeking implant-related assessment and treatment due to prior tooth loss for the purposes of function, appearance, and maintenance of the alveolus, but there are also individuals who have suffered trauma such as dental avulsion or tooth, jaw, or facial fracture. Such patients then may also be treated using implants or through various osteopathic techniques (like wiring a fracture of the mandibular body). In such cases tooth loss may or may not be related to the trauma itself but may be deemed suitable for long-term function. These cases are in addition to a large ratio of young patients with third molar extractions.

Assessment will be made solely by perusal of written patient files (which contain treatment details and personal information such as age and medication) and panoramic radiographs. All individuals will be assessed by the author and included only if both a known date of tooth loss and subsequent radiographs are available.

*Age and sex divisions*

The cohort will be assessed entirely and divided by chronological age and sex. Sex will be determined based on the individual's name and recorded as either male or female. Age at the time of tooth loss will be calculated from birth date in the patient's file for each socket (if more than one socket is recorded for a given individual). Individuals will be divided into three groups based on these data: under 20, 20 to 50, and over 50 years of age. These categories are intentionally broad in order to accommodate archaeological application and encapsulate pubertal and post-menopausal samples. Research indicates menarche occurs roughly between the ages of 12 and 14 regardless of race or location although it likely occurred later in past populations (Aw and Tye 1970; Cameron et al. 1991; Magnússon 1978; Shakir 1971; Stout and Lueck 1994; Tryggvadóttir 1994). Pubertal changes tend to be menarche-centric and so the spike in rates of bone modeling and remodeling is largely confined to the early to mid-teen years (Cadogan et al. 1998; Eastell 2005; Simondon et al. 1997). In males puberty is slightly later than in females but sex hormone production and the effects thereof has stabilized at adult rates usually by the later teen years (Matkovic 1996; Stout and Lueck 1995). Female menopause occurs in Caucasian populations approximately between 49 and 51; shortly thereafter bone steadily and considerably demineralizes, eventually resulting in systemic osteopenia and osteoporosis, and the rate of turnover and remodeling slows (Binte Anwar et al. 2007; Gold et al. 2001; Gosden 2007; Lerner 2006a; Reynolds and Obermeyer 2005). Male menopause consists of a more gradual decline of androgens but the effects on cellular bone dynamics begin to become apparent for men in their late 50s and are cumulative, with similar – if less severe – effects to female menopause (Morales et al. 2000; Vermeulen 2000).

*Exclusion criteria*

Exclusion will be performed based largely on circumstances which either interfere with socket healing or obscure the socket image. Those vitamin, mineral, physiological, and pathological factors which either accelerate or inhibit bone modeling or remodeling rates will be controlled for through the exclusion of individuals known to utilize such substances or be affected by such conditions discussed in 2.3. This would normally also include estrogen supplementation during and following menopause but its common use as hormone replacement therapy or for birth control means using it as a basis for exclusion would likely produce too small a female cohort.

Due to the rapid remodeling associated with tooth eruption individuals still undergoing eruption of the permanent dentition with the exception of the third molars will also be excluded. Although it would be ideal to include the third molars in this category their eruption can be slow and the desire to include individuals under the age of 20 years must take into consideration that many such individuals do not have erupted third molars at that time. Only teeth which are erupted or erupting will be considered; deciduous teeth would only be assessed if the respective permanent tooth was agenetic.

For each socket date of tooth loss and at least one clear post-extraction radiograph are required. Although multiple radiographs spanning at least several months would be ideal rejection will not occur on the basis of when the film was taken or how many there are provided that there is at least one within five years of tooth loss. Multiple sockets remodeling concurrently and completely edentulous jaws or individuals will not be rejected provided it is possible to distinguish between individual sockets. A damaged socket, one which is overwhelmed by an active affiliated alveolar defect or cyst, or one through which a jaw fracture passes will also be rejected but periodontitis and small defects will not be justification for exclusion.

### 3.3 Statistical Analyses

The use of statistical methods of data analysis will be directed towards the primary goal of linking TSL with stage of fullness. To that end cluster analysis will be coupled with ANOVA and descriptive statistics. The latter of these will provide an overview of the data present and show skewing towards a certain variable value over another. Clustering will provide answers to the core question of the links between TSL and stage of fullness and subsequent investigation into TSL variation within a specific variable (such as sex) or group of variables (such as sex and age) will indicate whether this variation is statistically significant. All tests will be performed by the author using Open Office or the SPSS 15.0 statistics package. Should weighting be deemed statistically necessary it will be undertaken by proportionally increasing the underrepresented sample group(s).

*Descriptive statistics*

Descriptive statistics will be applied in many forms at different stages of the data analysis. Initially graphs of age and sex distributions of the cohort as well as distributions of sockets recorded by location, presence of neighboring and occlusal teeth, fullness, radiolucency, and TSL will provide an understanding of the raw data. An image of relationships between certain variables, such as fullness and TSL, can also be created with scatter plots. These results will indicate whether or not it may be necessary to weight the data in one direction (such as towards males) in order to compensate for insufficiencies (i.e. overabundance of female samples) in the total dataset. Following the other statistical tests line graphs of average TSL values for specific values of specific variables may be plotted to see how they compare with other values, other variables, or the averages for the whole sample. This will allow the visualization of a value's influence on the normal rate of socket healing.

*Cluster analysis*

A cluster analysis which assesses TSL and stage of fullness as the sole variables will then group all samples based on similarities between them: groups may be identified which consist exclusively of one or more specific TSLs or stages of fullness or each group may consist of multiple values of each variable. As part of the analysis each sample will then be assigned a cluster and further testing will be performed separately on different clusters: this will prevent false significance results in subsequent tests on variables. Although the statistical significance of cluster distribution is not calculated this will be assured through an ANOVA of the entire sample performed on TSL and cluster designation. Ideally there will be more than one cluster and they will follow a clear remodeling pattern to be easily distinguishable from one another based on fullness; TSL values will then be averaged for the entire cluster to provide an estimation value. If this is not the case then additional variables may be included to see if they stabilize the tested sample.

*ANOVAs and linear models*

One-way ANOVAs will be performed on the TSLs for each variable for each cluster and will indicate whether the intra-variable variation in TSL value is significant or not. A significant result indicates both that the values are nonrandom and that the variation is broad enough that the samples should be further distinguished between; this is usually satisfied by dividing samples by their assigned values in the variable being tested. TSL values will then be averaged for each value of each variable for each cluster, and those of the significant variables will be included in TSL estimation as mitigating factors in the usual progression of socket healing.  Linear models will be created to similarly determine the significance of variation of the TSL values of multiple variables.

### 3.4 Testing

Data were collected on-site by the author at the aforementioned dental practice in Fulda, Germany, from October 2009 to January 2010.  The previously established methodology was followed with minor ad hoc changes.  Patient files were selected by staff at the practice.  Approximately 250 patients were assessed in order to determine their suitability for this project.  In addition to the previously outlined criteria sockets were also rejected if there was an active associated osteomyelitic defect which was larger than one-quarter the size of the initial socket – sometimes estimated by size of neighboring tooth roots.  Finally, occasional difficulties in distinguishing between bone and some soft tissues within the socket were resolved with the inclusion of stage of radiolucency of the new bone.  It became quickly apparent that vascularization structure and luminescence of newly modeled bone had a clear pattern of development with the osseous healing of the socket over time.

General individual data consisted of an identification number assigned by the practice (for differentiation and in order to return to the patient file if necessary) along with sex and date of birth.  Age at the time of tooth loss was calculated for each socket.  Some medications and systemic conditions (diabetes, etc.) were intended to serve as exclusion criteria but the relevant notes in patient files tend to be inconsistent.  With this in mind medications and conditions have been recorded but will not be factors in analyses or serve as tools for exclusion.  A basic dental inventory differentiated between present, absent, unerupted, impacted, and agenetic teeth as well as the presence of braces or a permanent retainer; all teeth are classified by the FDI system.  Due to general clinical recording standards dental health was not assessed.  Socket-specific data consisted of information on the initial tooth loss (date, cause and reason, any interference, and details of treatment) and each follow-up visit for which a clear radiograph was available within the following five years; on occasion this was the day after extraction.  All follow-ups within this time period were recorded until both terminal stages of both fullness and radiolucency had been observed. Information gathered was derived from both the written record and the radiograph (date, stages of fullness and radiolucency, any complications, and details of new treatments at the site).  Samples were defined by follow-up (specifically stage of fullness and TSL); each follow-up comprised a single sample consisting of up to 57 points.  The form utilized has been reproduced in Table 3.4.1 and photographs of examples of the individual fullness and radiolucency stages have been provided for reference in Figures 3.4.1-2.

**Table 3.4.1 Phase 1 Data Collection Form**

*individual and general data*

| ID | Birth date | Sex | Medications | Conditions | Tooth loss |
|---|---|---|---|---|---|
| 12345 | 11/12/85 | F | none | asthma | 2 |
| | | | | | # teeth previously lost or extracted |

*dental inventory*

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| **18** | **17** | **16** | **15** | **14** | **13** | **12** | **11** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** |
| **48** | **47** | **46** | **45** | **44** | **43** | **42** | **41** | **31** | **32** | **33** | **34** | **35** | **36** | **37** | **38** |
| 2 | 1 | 1 | 1 | 1* | 1* | 1* | 1* | 1* | 1* | 1* | 1* | 1 | 1 | 1 | 2 |

| | |
|---|---|
| 1 | present |
| 2 | previously lost/extracted |
| 3 | agenetic |
| 4 | erupting |
| 5 | unerupted/in crypt |
| 0 | tooth to be extracted/socket recorded |
| * | indicates a brace or permanent retainer anchor |

*extraction/loss site*

| Site | Loss date | Age at loss | Age category | Neighboring teeth | | |
|---|---|---|---|---|---|---|
| | | | | Mesial | Distal | Occlusal |
| 28 | 18/10/2009 | 24 | 2 | 1 | 3 | 1 |
| tooth | | | 1 <20 | 1 Present | | |
| | | | 2 20-50 | 2 Absent | | |
| | | | 3 >50 | 3 3rd Molar (distal only) | | |

| Reason for loss/extraction | Interference | Treatment |
|---|---|---|
| 1 | 0 | 1, 7 (decongestant) |
| 1 caries | 1 alveolar defect | 1 antibiotics |
| 2 periodontal disease | 2 periodontitis | 2 NSAIDs |
| 3 orthodontics | 3 sinusitis | 3 analgesics |
| 3a third molar crowding | 4 jaw fracture | 4 antiseptic rinse |
| 4 impaction or maleruption | 0 none | 5 chlorhexidine-containing rinse |
| 5 trauma | | 6 collagen |
| | | 7 other |

**Table 3.4.1 continued on next page**

**Table 3.4.1 (continued from previous page)**

*follow-up*

| Date | Time since loss (TSL) | Fullness | Radiolucency | Complications | Treatment |
|---|---|---|---|---|---|
| 01/04/2010 | 24 | 5 | 4 | 1 | 0 |
| | in weeks | 1 no bone formation | 1 black, no new bone | 1 none | 1 antibiotics |
| | | 2 apex - ¼ full | 2 very pale shadow, not vascularized | 2 local inflammation | 2 NSAIDs |
| | | 3 ¼ - ½ full | 3 pale, finely vascularized | 3 local defect, infection | 3 analgesics |
| | | 4 ½ - ¾ full | 4 same color as alveolus, fine/bilious vascularization | 4 alveolar osteitis | 4 antiseptic rinse |
| | | 5 ¾ full - depression | 5 color and internal structure match with surrounding alveolus | 5 other | 5 chlorhexidine-containing rinse |
| | | 6 level alveolus | | | 6 collagen |
| | | | | | 7 other |

A reproduced version edited for formatting purposes of the data collection form utilized for phase 1. Codes and necessary descriptions are noted and an example is in gray.

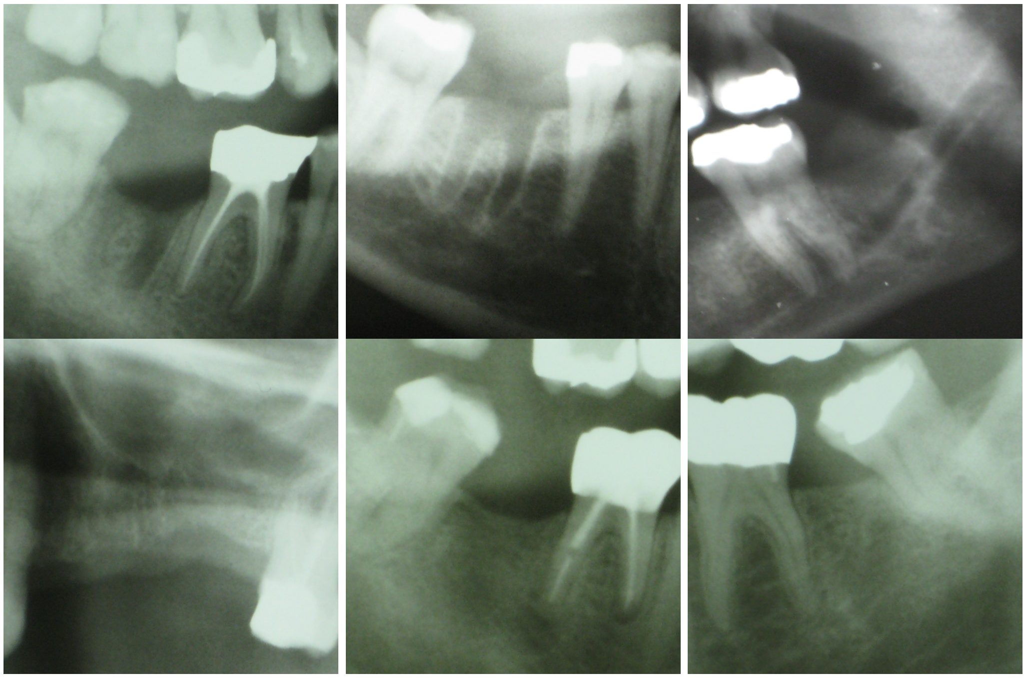

**Figure 3.4.1 Phase 1 Data Collection: Stages of Fullness**
From left to right, top row: stage 1, no bone formation; stage 2, new bone formation at apex/borders to socket ¼-filled; stage 3, socket ¼- to ½-filled. Bottom row: stage 4, socket ½- to ¾-filled; stage 5, socket ¾-filled to full but with a depression still present; stage 6, socket completely filled with level alveolus.

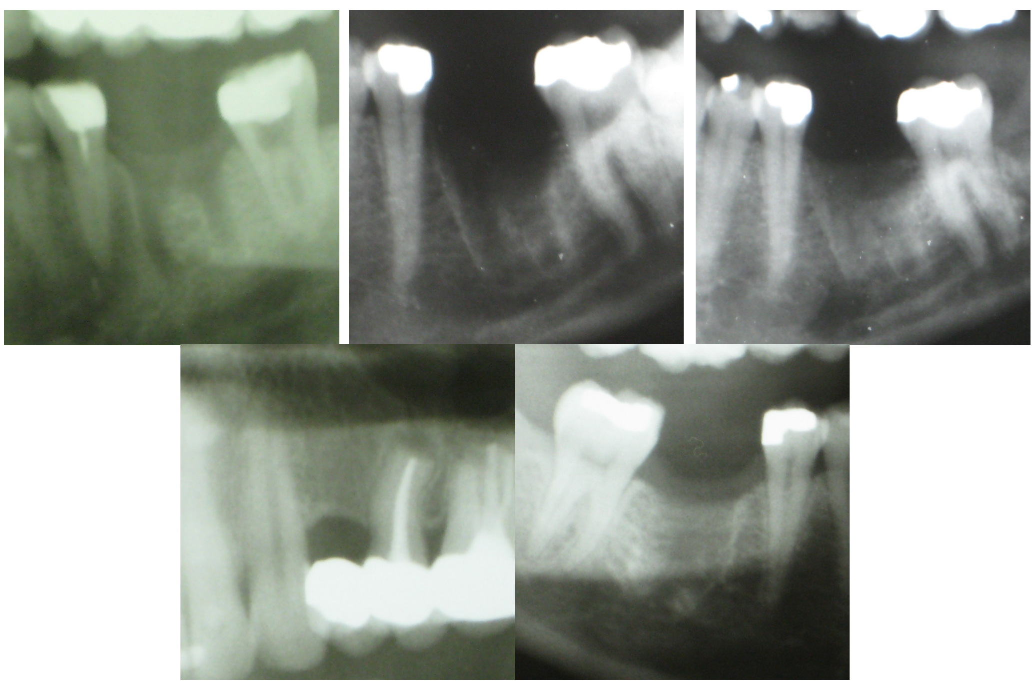

**Figure 3.4.2 Phase 1 Data Collection: Stages of Radiolucency**
From left to right, top row: stage 1, new bone not present or is black (not osseous); stage 2, new bone is a very pale shadow without apparent vascularization; stage 3, new bone is paler and vascularization is finer than the surrounding bone. Bottom row: stage 4, new bone is a color match to the surrounding bone but the vascularization is still more fine or bilious in comparison; stage 5, new bone is a match to the surrounding alveolus in both color and trabecular structure.

## CHAPTER 4 PHASE 1 RESULTS

Data collection and analysis techniques were, for the most part, successful, with ad hoc alterations to the initial project plan outlined in full in section 3.4 above. Data analysis was performed following all data collection for this stage in order to avoid observed sampling bias (for example, an exclusion of females in the later stages of data collection in order to better balance the sex distribution). The final dataset consisted of 116 sockets, all removed by extraction, with an overabundance of samples from the second age category and males. Socket location distributions were also very uneven particularly with regard to the third molar position (64% of all sockets) and the rest of the dentition: as some 51% of the sockets were extracted due to third molar crowding or maleruption this is neither surprising nor ideal. Because the dataset is skewed in this direction some of the more site-specific comparisons that were sought were statistically insupportable.

Following the exploratory investigations of the data a bivariate cluster analysis of TSL and fullness values in the entire sample produced three clusters clearly delineated by stage of fullness. The first consists of sockets in the first stage of fullness (pre-osseous healing); the second with those from the second to fourth stages of fullness (osseous remodeling); and the third with those from the fifth and sixth stages of fullness (ossified/healed). Although TSL values for samples in second cluster were later found to vary significantly with regard to fullness, those in the final cluster were not. Most variables were found to exhibit significant TSL variation for at least one cluster (as assessed by ANOVA). Four linear models were also created in order to group certain variables; these were composed of sex and age, neighboring tooth status, and various treatments at the time of extraction or follow-up and only the former two were found to exhibit statistically significant variation.

This was in keeping with significance results for the individual variables. Further and more elaborate desired variable groupings (such as those consisting only of selected values of multiple variables) were not possible due to sample size and distribution. Practical application of these findings will be based on averages for a given value, variable, and cluster where the variable was found to exhibit significant TSL value variation for the cluster; the 5% most extreme TSL values have been trimmed from each of these averages to increase precision and avoid mathematical bias.

### 4.1 Data Distributions

Data were collected from and analyzed on 198 follow-ups for 116 sockets from 46 individuals. Each individual was linked with at least one socket and at least one follow-up; the largest number of sockets recorded for a single individual was 11 and the largest number of follow-ups recorded for a single socket was 7. On average approximately 2.5 sockets were recorded for each individual and 1.7 follow-ups for each socket. When sockets are classified by age and sex only 12% of sockets are from individuals over the age of 50 at the time of tooth loss and more than half are from the second age category. Males and females are represented at an approximate ratio of 3 to 2. Age category and sex distributions for the cohort are outlined in Table 4.1.1 and displayed in Figures 4.1.1 and 4.1.2, respectively. Although skewed distributions they are satisfactory considering the small sample size.

**Table 4.1.1 Socket Distribution by Age Category and Sex**

| | Male | Female | Total |
|---|---|---|---|
| **<20** | 24 | 14 | 38 |
| **20-50** | 49 | 15 | 64 |
| **>50** | 6 | 8 | 14 |
| **Total** | 79 | 37 | 116 |

Distributions of recorded sockets by the patient's sex and age category (at the time of tooth loss).

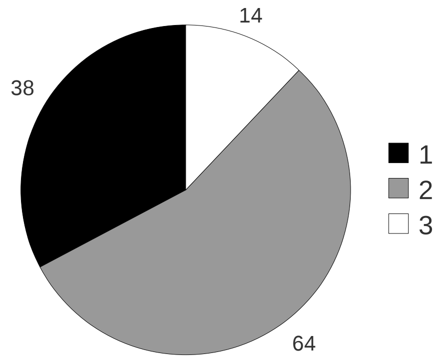


**Figure 4.1.1 Socket Distribution by Age Category**
Distribution of recorded sockets by individual age at the time of tooth loss. Sockets created by the loss of a tooth before the age of 20 years are in black, those by loss between 20 and 50 in gray, and those by loss after 50 in white.

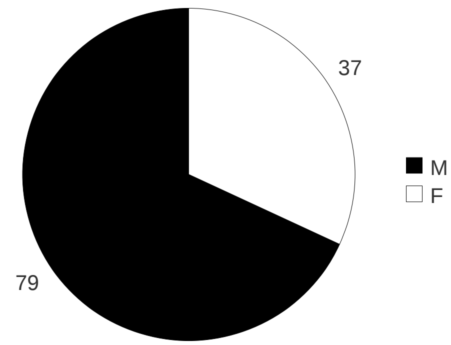


**Figure 4.1.2 Socket Distribution by Sex**
Distribution of recorded sockets by individual sex.

Sockets are further distributed unevenly in terms of site. There are very few anterior teeth in comparison to posterior teeth (Figure 4.1.3) with no more than three examples for any non-molar site (Table 4.1.2). There is particular dominance by sockets from third molars (Figure 4.1.4): this is due to multiple patients with third molar maleruption or anticipated crowding which is treated with extraction of usually all four third molars. Because of this high proportion of third molar extractions the reasons recorded for extraction are dominated by orthodontics (58%) with local disease treatment/prevention (caries and periodontal disease for a combined 33% of recorded sockets) responsible for most of the rest of the sample (Figure 4.1.5). Unexpectedly only three sockets were the result of trauma and these from one individual who suffered multiple mandibular fractures and for whom the teeth were extracted to avoid compromising fracture healing.

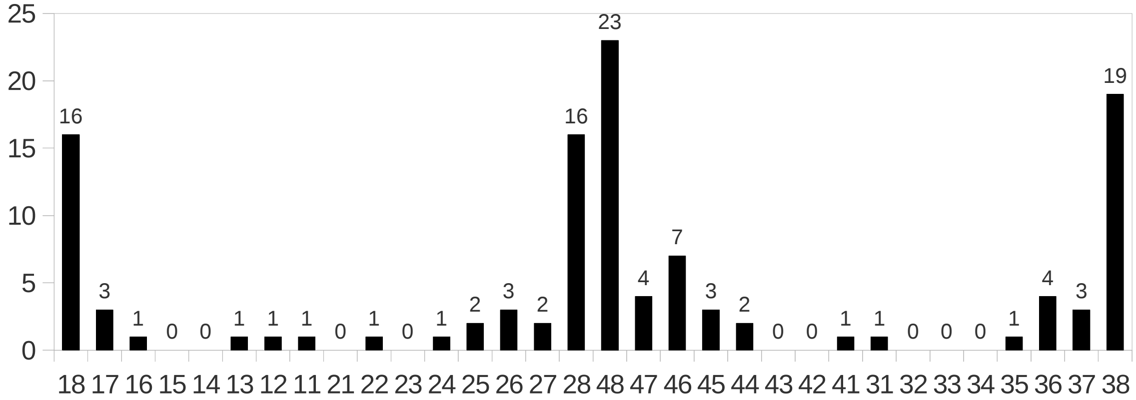


**Figure 4.1.3 Socket Distribution by Site**

A visual depiction of the distribution of recorded sockets by tooth site.

**Table 4.1.2 Socket Distribution by Site**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total | Jaw |
|---|---|---|---|---|---|---|---|---|---|---|
| **Arch 1** | 1 | 1 | 1 | 0 | 0 | 1 | 3 | 16 | **23** | 48 |
| **Arch 2** | 0 | 1 | 0 | 1 | 2 | 3 | 2 | 16 | **25** | |
| **Arch 3** | 1 | 0 | 0 | 0 | 1 | 4 | 3 | 19 | **28** | 68 |
| **Arch 4** | 1 | 0 | 0 | 2 | 3 | 7 | 4 | 23 | **40** | |
| **Total** | **3** | **2** | **1** | **3** | **6** | **15** | **12** | **74** | **116** | |
| **Type 1** | 5 | | 1 | 9 | | 101 | | | **Rights** | 63 |
| **Type 2** | 6 | | | 110 | | | | | **Lefts** | 53 |

Distributions of recorded sockets by tooth site. Seven different categorizations – site (e.g. 11, 12), site number (e.g. 1, 2), arch number (e.g. arch 1, arch 2), jaw (mandible, maxillae), side (right, left), group type 1 (incisors, canines, premolars, molars) and group type 2 (anterior, posterior) – may be utilized in statistical analyses in order to identify any differences in healing rates between sites.

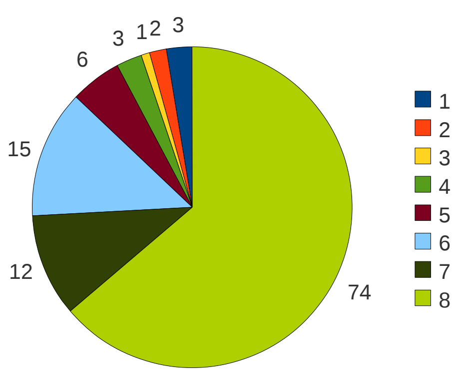


**Figure 4.1.4 Socket Distribution by Site Number**

Distributions of recorded sockets by site number irrespective of arch.

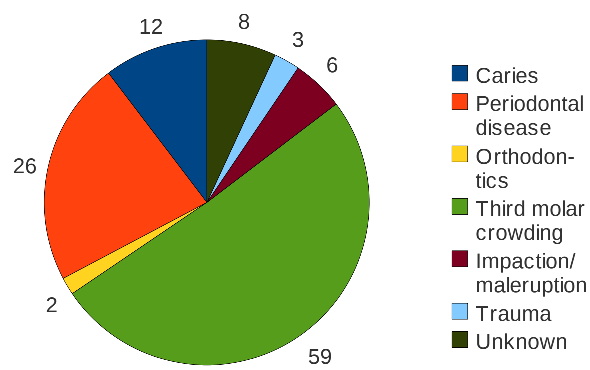


**Figure 4.1.5 Reason for Tooth Extraction**

Reasons for tooth extraction for all recorded sites as noted in patient files. Note that all recorded causes of tooth loss are reasons provided for extraction with the exceptions of trauma, where the tooth was either irreplaceably avulsed or otherwise irreparably damaged, and unknown, where cause of tooth loss was not recorded.

Distributions of fullness and radiolucency stages for each follow-up are displayed in Figures 4.1.6 and 4.1.7. In the former the first stage (no osseous development) dominates slightly with 35% of all follow-ups assigned this score. This is due to a high number of follow-ups immediately or one day following extraction. Radiolucency scores however are not similarly distributed but instead appear fairly balanced.

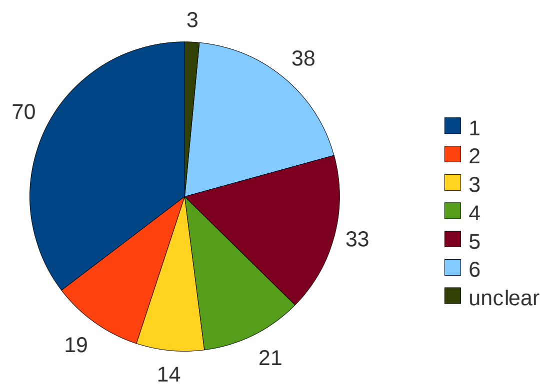


**Figure 4.1.6 Distribution of Socket Fullness Scores**
Distributions of socket fullness scores for all sockets and from all follow-ups. Stage 1 no bone formation; stage 2 new bone formation at apex to socket ¼-filled; stage 3 socket ¼- to ½-filled; stage 4 socket ½- to ¾-filled; stage 5 socket ¾-filled to full but with a depression still present; stage 6 no indication of socket, alveolus level.

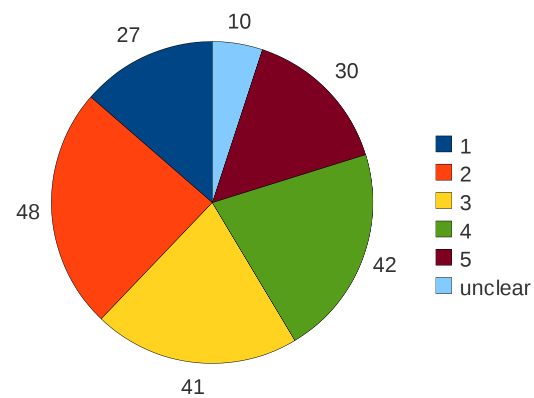


**Figure 4.1.7 Distribution of Socket Radiolucency Scores**
Distributions of socket radiolucency scores for all sockets and from all follow-ups. Stage 1 no new bone; stage 2 very pale osseous shadow without apparent vascularization; stage 3 new bone is paler and vascularization is finer than surrounding bone; stage 4 new bone is a color match to surrounding bone but vascularization is still finer or more bilious in comparison; stage 5, new bone is a match to surrounding bone.

## 4.2 Statistical Analyses

More complex statistical tests were performed in order to understand the relationship between assigned stage of fullness and TSL, estimate the significance of variability of TSL values for all variables, and provide reliable TSL estimates for a given stage of fullness with regard to variables which have a significant bearing on TSL. These relationships were assessed through the use of bivariate clustering, ANOVA, general linear models, and finally five-percent-trimmed averages.[10]

Initial cluster analysis produced three clusters delineated by stage of fullness – an ideal result. The first cluster (fullness stage 1) comprises sockets which have yet to display evidence of osseous healing (although regenerative soft tissue activity would have already begun). The second (fullness stages 2-4) consists of sockets with initial osseous healing to those which have ossified no more than approximately three-quarters: an ANOVA indicates that there is significant TSL variation between these stages of fullness and so it would remain useful to discriminate between these stages in practical application. The third cluster (fullness stages 5-6) is composed of sockets which are fully ossified: although the final crest of the socket still has yet to ossify in stage 5, an ANOVA found insignificant TSL variation between these two stages of fullness and so such sockets may be deemed fully remodeled. Other ANOVAs found significant intra-variable variation for at least one cluster in most variables; two multivariable groups (sex-age and neighboring teeth statuses) were also found to exhibit significant variation for given clusters in only the second and third clusters by linear modeling.

Prediction of TSL based on stage of fullness and variables with significant variation for a given cluster was limited by sample sizes for some values of these variables. This was most problematic for the treatment variables (which will not apply to archaeological application). The findings do however allow for limited practical application of these results without further investigation in clinical and forensic contexts. For the purposes of

[10] The trimmed value is the average TSL excluding the most extreme 5% of cases within the sample. This value is more reliable because it is less likely to be artificially high or low due to extreme values.

phase 2 to further elucidate the appearance of remodeling sockets in (archaeological) dry bone they are reasonable and reliable.

*Clustering*

Initial analyses of the data were undertaken with the use of bivariate clustering where TSL value was compared with stages of fullness (Figure 4.2.1). The results clearly distinguished three clusters which divide the sample based on stage of fullness so that all samples for a given fullness stage are categorized together (Table 4.2.1). The first cluster consists of samples recorded during the first stage of fullness – before soft tissues are replaced by bone – and the average TSL is 3 weeks or 2 weeks trimmed. The second cluster consists of samples recorded during the second, third, and fourth stages of fullness – during the bony modeling phase – and the average TSL is 15 weeks or 14 weeks trimmed. The final cluster consists of samples recorded during the fifth and sixth stages of fullness – essentially the healed phase – and the average TSL is 80 weeks or 78 weeks trimmed.

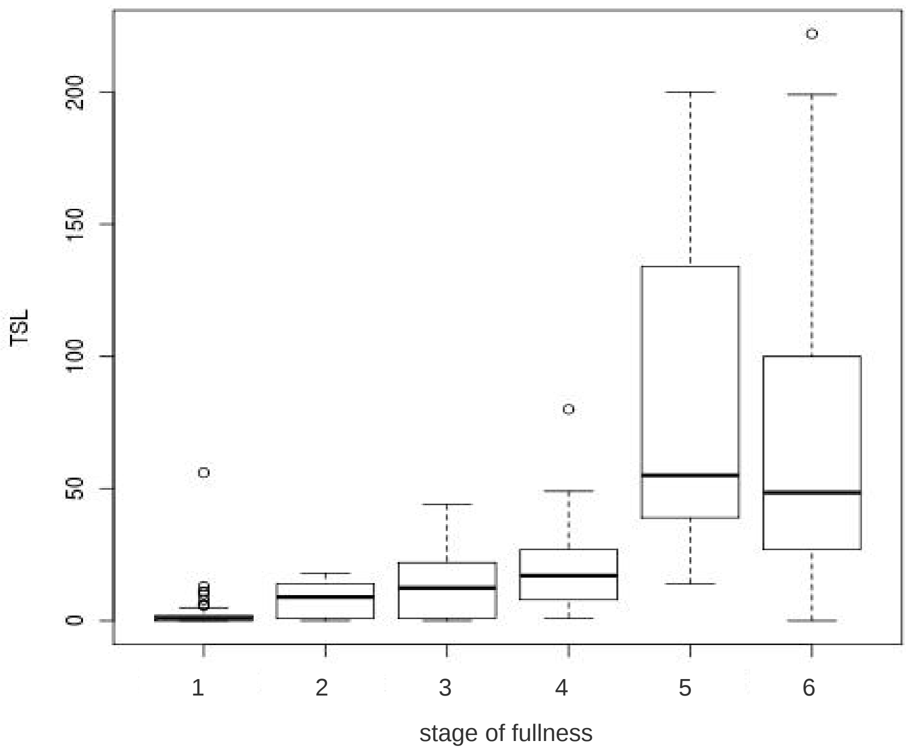


**Figure 4.2.1 Progression of Fullness Stage with Increasing TSL**
Box plots of all socket samples. From these data cluster analysis classified three clearly-defined clusters: the first includes all samples from stage 1, the second all samples from stages 2-4, and the third all samples from stages 5 and 6.

**Table 4.2.1 Cluster Characteristics**

| Cluster | Stage of Fullness | # Samples | TSL | Standard deviation | TSL range | Trimmed TSL |
|---|---|---|---|---|---|---|
| **1** | 1 | 70 | 3 | 7 | 0-10 | 2 |
| **2** | 2, 3, 4 | 55 | 15 | 15 | 0-30 | 14 |
| **3** | 5, 6 | 71 | 80 | 65 | 15-145 | 78 |

Details of clusters derived from cluster analysis of all samples by stage of fullness and TSL. All times are in whole weeks; range is derived from positive and negative standard deviations from TSL value. Trimmed TSL values are 5% trimmed averages: the 5% most extreme cases are excluded.

*Influence of variables*

Four univariate linear models were formulated to assess the significance of intra-cluster TSL variation for two or more variables. The results are in Table 4.2.2. The significance of intra-cluster TSL variation for each of the 34 variables was assessed by ANOVAs. The results are in Table 4.2.3. Trimmed averages for each value of variables deemed significant by ANOVA are in Table 4.2.4. Note that some variables with significant variation in Table 4.2.3 are absent from Table 4.2.4: this is because their values were insufficiently represented either due to a complete absence of samples or simply too few (<4) to calculate a trimmed value. These have therefore been excluded regardless of significance. Where samples have constant TSL values derived from at least four samples for each variable value however their trimmed averages have been listed. Comprehensive tables of all results including sample sizes, significance, standard deviations, and trimmed and untrimmed averages for all values for all variables and clusters are in the Appendix.

**Table 4.2.2 Significance Results of Linear Models of Selected Variable Groups**

| Variables | Cluster 1 | Cluster 2 | Cluster 3 |
|---|---|---|---|
| Sex and age | insignificant | $p<0.01$ | $p<0.01$ |
| Mesial, distal, and occlusal tooth presence | insignificant | $p<0.05$ | $p<0.01$ |
| All forms of treatment (except no treatment) at the time of extraction | insignificant | insignificant | insignificant |
| All forms of treatment (except no treatment) at follow-up | insignificant | insignificant | insignificant |

Significance of intra-cluster variation of TSL for multiple variables assessed by general linear models. Variation is insignificant where $p>0.05$.

**Table 4.2.3 Significance Results of ANOVAs on Variables**

| Variables | | Cluster 1 | Cluster 2 | Cluster 3 |
|---|---|---|---|---|
| Sex | | insignificant | p<0.05 | p<0.01 |
| Age | | insignificant | insignificant | p<0.01 |
| Number of teeth lost | | insignificant | insignificant | p<0.01 |
| Socket location | site | insignificant | p<0.01 | p<0.05 |
| | arch | insignificant | p<0.01 | insignificant |
| | site # | insignificant | p<0.01 | p<0.01 |
| | jaw | insignificant | insignificant | insignificant |
| | side | insignificant | p<0.01 | insignificant |
| | category 1 | insignificant | insignificant | insignificant |
| | category 2 | insignificant | insignificant | insignificant |
| Neighboring tooth status | mesial tooth presence | insignificant | insignificant | insignificant |
| | distal tooth presence | insignificant | p<0.05 | p<0.05 |
| | occlusal tooth presence | insignificant | p<0.01 | insignificant |
| Reason for extraction | | insignificant | insignificant | p<0.05 |
| Socket interference | | insignificant | insignificant | p<0.05 |
| Treatment at the time of extraction | none | insignificant | insignificant | p<0.01 |
| | with antibiotics | insignificant | insignificant | insignificant |
| | with NSAIDs | insignificant | insignificant | insignificant |
| | with analgesics | insignificant | p<0.01 | insignificant |
| | with non-chlorhexidine-containing antiseptic rinse | insignificant | insignificant | p<0.05 |
| | with chlorhexidine-containing rinse | insignificant | insignificant | insignificant |
| | with collagen | insignificant | insignificant | insignificant |
| | with other (unclassified) medication | insignificant | insignificant | insignificant |
| Stage of fullness | | | p<0.05 | insignificant |
| Stage of radiolucency | | insignificant | P<0.05 | p<0.01 |
| Complications recorded at follow-up | | insignificant | insignificant | insignificant |
| Treatment at follow-up | none | insignificant | insignificant | insignificant |
| | with antibiotics | insignificant | p<0.05 | insignificant |
| | with NSAIDs | insignificant | | |
| | with analgesics | insignificant | insignificant | |
| | with non-chlorhexidine-containing antiseptic rinse | insignificant | insignificant | insignificant |
| | with chlorhexidine-containing rinse | p<0.05 | insignificant | insignificant |
| | with collagen | insignificant | insignificant | |
| | with other (unclassified) medication | insignificant | insignificant | |

Significance of variation of TSL for the values of a given variable assessed by ANOVA. Variables for which insufficient samples were available or only samples for a single value of the variable are available (such as fullness for cluster 1 as all samples within cluster 1 are fullness stage 1) are in gray. Variation is insignificant where p>0.05.

**Table 4.2.4 Trimmed TSL Averages for Values of Significant Variables by Cluster**

| Variable | Value | Cluster 1 | | Cluster 2 | | Cluster 3 | |
|---|---|---|---|---|---|---|---|
| | | n | TSL | n | TSL | n | TSL |
| Sex | male | | | 29 | 10 | 39 | 108 |
| | female | | | 26 | 18 | 32 | 46 |
| Age | <20 | | | | | 17 | 52 |
| | 20-50 | | | | | 36 | 117 |
| | >50 | | | | | 18 | 31 |
| Arch | 1 | | | 9 | 7 | | |
| | 2 | | | 12 | 13 | | |
| | 3 | | | 21 | 22 | | |
| | 4 | | | 13 | 9 | | |
| Side | right | | | 22 | 8 | | |
| | left | | | 33 | 18 | | |
| Distal tooth | present | | | 10 | 13 | 26 | 69 |
| | absent | | | 10 | 25 | 20 | 111 |
| | distalmost | | | 35 | 12 | 25 | 59 |
| Occlusal tooth | present | | | 17 | 21 | | |
| | absent | | | 38 | 10 | | |
| Interference* | no interference | | | | | 39 | 67 |
| | alveolar defect | | | | | 28 | 101 |
| Any treatment at the time of extraction? | yes | | | | | 35 | 54 |
| | no | | | | | 36 | 104 |
| Application of non-chlorhexidine containing antiseptic rinse at the time of extraction? | yes | | | | | 58 | 86 |
| | no | | | | | 13 | 43 |
| Stage of fullness | 2 | | | 19 | 8 | | |
| | 3 | | | 14 | 14 | | |
| | 4 | | | 21 | 20 | | |
| Stage of radiolucency* | 4 | | | | | 33 | 56 |
| | 5 | | | | | 28 | 117 |
| Treatment with antibiotics at follow-up? | yes | | | 35 | 17 | | |
| | no | | | 20 | 9 | | |
| Application of chlorhexidine-containing rinse at follow-up? | yes | 29 | 3 | | | | |
| | no | 41 | 1 | | | | |

Five percent trimmed TSL averages for each value of those variables which exhibit statistically significant TSL variation. Averages are only provided for those values which have sufficient sample sizes (≥4). *There are insufficient samples for this variable with the exception of these values.

## 4.3 TSL Estimation

The problem with the above data is that they are simply a reflection of the sample based on arbitrary TSL limitations ($0 \geq TSL \leq 260$). Had the maximum TSL exclusion point been two years after tooth loss instead of five it is likely the third category would not be as erratic or display such variation with regard to certain variables. Where TSL is unknown this is an impractical distinction: in archaeological samples for example the first cluster would not be identified at all, as sockets without osseous healing are identified as having been voided by the tooth postmortem, and maximum TSL may be decades. With this in mind a remodeling-centric schedule has been developed and reproduced in Table 4.3.1. It is derived from the second cluster as it is characterized solely by stage of fullness and so lacks arbitrary TSL boundaries, the boundaries instead being between pre-osseous and remodeling, remodeling and remodeled stages. Utilizing the trimmed average as a preliminary estimator and the standard deviation in order to predict (1) the lower boundary before which sockets can be presumed to lack apparent osseous healing and (2) the upper boundary beyond which sockets can be presumed to be completely ossified corrects this sampling bias. The TSLs for the first cluster are maximums (i.e. a socket assigned the first cluster where the occlusal tooth is present was lost no more than three weeks ago) and for the third are minimums (i.e. the same socket after ossification is complete, provided the occlusal tooth is still present, was lost at least 39 weeks ago). Only those values with sufficient sample sizes and of variables which exhibit significant TSL variation for the second cluster have been included; it is not possible to calculate stage of fullness values for the first and third cluster as they and the second cluster values are mutually exclusive. Comprehensive tables of all results including trimmed and untrimmed TSL calculations for all values for all variables are in the Appendix.

**Table 4.3.1 Remodeling-centric TSL Estimation by Cluster**

| Variable | Value | Cluster 1 TSL | Cluster 2 TSL | *Standard deviation* | Cluster 3 TSL |
|---|---|---|---|---|---|
| Cluster | 1 | 0* | | | |
| | 2 | | 14 | *15* | |
| | 3 | | | | 29 |
| Sex | male | 0* | 10 | *12* | 22 |
| | female | 1 | 18 | *17* | 35 |
| Arch | 1 | 0 | 7 | *7* | 14 |
| | 2 | 1 | 13 | *12* | 25 |
| | 3 | 3 | 22 | *19* | 39 |
| | 4 | 1 | 9 | *8* | 17 |
| Side | right | 0 | 8 | *8* | 16 |
| | left | 1 | 18 | *17* | 35 |
| Distal tooth | present | 5 | 13 | *8* | 21 |
| | absent | 2 | 25 | *23* | 48 |
| | distalmost | 0* | 12 | *13* | 25 |
| Occlusal tooth | present | 3 | 21 | *18* | 39 |
| | absent | 0* | 10 | *12* | 22 |
| Stage of fullness | 2 | | 8 | | |
| | 3 | | 14 | | |
| | 4 | | 20 | | |
| Treatment with antibiotics at follow-up? | yes | 0 | 17 | *17* | 34 |
| | no | 0* | 9 | *10* | 19 |

Remodeling-centric TSLs for each value with sufficient sample sizes (≥4) of those variables which exhibit statistically significant TSL variation in the second cluster. The second cluster TSLs are trimmed averages; standard deviations are from the second cluster. The first cluster TSLs are calculated by subtracting the standard deviation from the second cluster TSL; the third cluster TSLs are calculated by adding the standard deviation to the second cluster TSL for each given value. *The calculated TSL was negative and has been amended to 0.

# CHAPTER 5 PHASE 1 CONCLUSIONS

For the purposes of most applications the remodeling-centric schedules will provide more reliable, useful, and practical results. Only where the study has a similar arbitrary post-extraction time limit as the data analyzed here would the limited schedules be useful; phase 2 will utilize the remodeling-centric schedules. For both versions however three stages or clusters of osseous remodeling have been derived: (1) pre-osseous healing, (2) bony modeling and remodeling, and (3) fully ossified. Application methodology also takes into consideration both significant TSL variation of certain variables and the sample size upon which that significant result is based. In general the experiment was a success in that it is now possible to estimate TSL in remodeling sockets as well as minimum TSL in remodeled sockets either solely from broad stages of socket fullness or in conjunction with additional variables.

In terms of variables a few results stand out in particular: neighboring tooth absence for example was found to significantly delay healing and sockets from the right side and the anterior dentition healed more swiftly. These findings may be attributable to mastication force dynamics and their effects on general alveolar remodeling; sampling bias may also play a role. Finally the insignificance of variation between fullness stages five and six indicates that sockets which may appear to still be modeling have in fact completely healed (in agreement with Schropp et al. 2003).

## 5.1 Limitations

Despite lacking the confirmation successful repetition of these methods and results would bring it is more than feasible to estimate the reliability of certain results. Some are clearly influenced by sampling bias: the skewness of the demographic distributions for example may have resulted in false positives in significance tests just as insufficient sample sizes for each value of a given variable within a specific cluster may obscure true inherent variation. Only further testing can confirm or refute any such claims accurately. Independent variables with sufficient and balanced sample sizes and statistically significant variation within a given cluster can be considered reliable. For best results the remodeling-centric schedules should also be used as these provide more definitive distinctions between the clusters rather than the sometimes severe overlapping of TSL estimates from one cluster to another in the limited-TSL schedules.

*Schedules*

The inclusion of standard deviations into the remodeling-centric schedules in particular means they are far less likely to erroneously predict TSL than the less precise limited-TSL schedules where standard deviations can overlap substantially between clusters. (For clinical application however this may be more suitable to allow for individual variation.) This distinction is made clearer by visual depictions: timelines of the limited-TSL (Figure 5.1.1) and the remodeling-centric (Figure 5.1.2) schedules are below. The erratic data in the third cluster data for the former schedule as it is a reflection of the cohort and so is subject to vast variation due to certain inherent methodological biases. These are caused by the arbitrary TSL limitations – at no point does a fully ossified socket become more ossified. One aim of application is to be able to give a minimum TSL for a fully-remodeled socket, and this is possible using the remodeling-centric schedules.

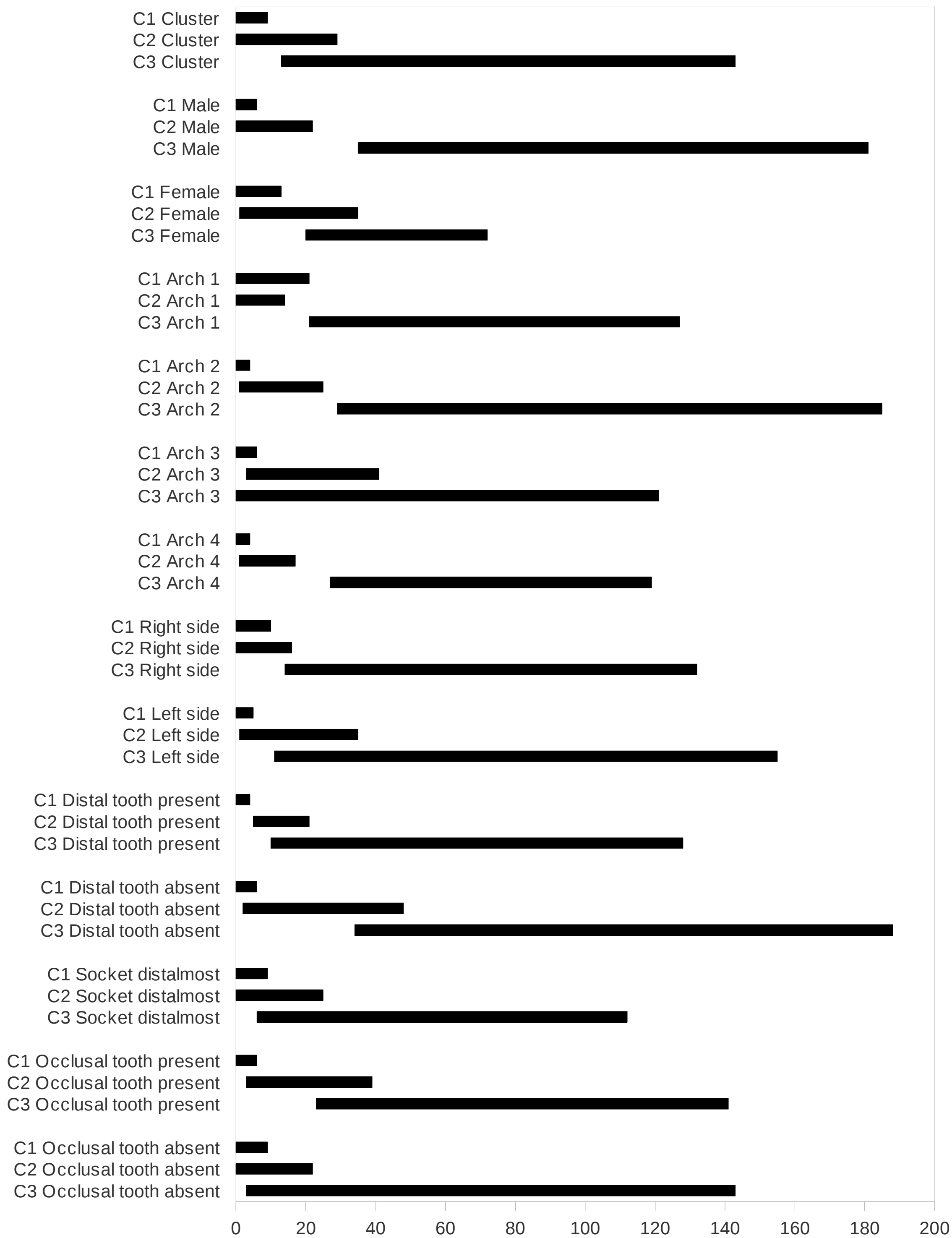


**Figure 5.1.1 Limited-TSL Healing Timelines of Selected Variables**

Timelines displaying the overlaps between clusters (C1, C2, C3) of specific values for each variable which contain significant variation for the second cluster (in order to more easily compare with Figure 5.1.2). Ranges are one standard deviation above and below the trimmed average.

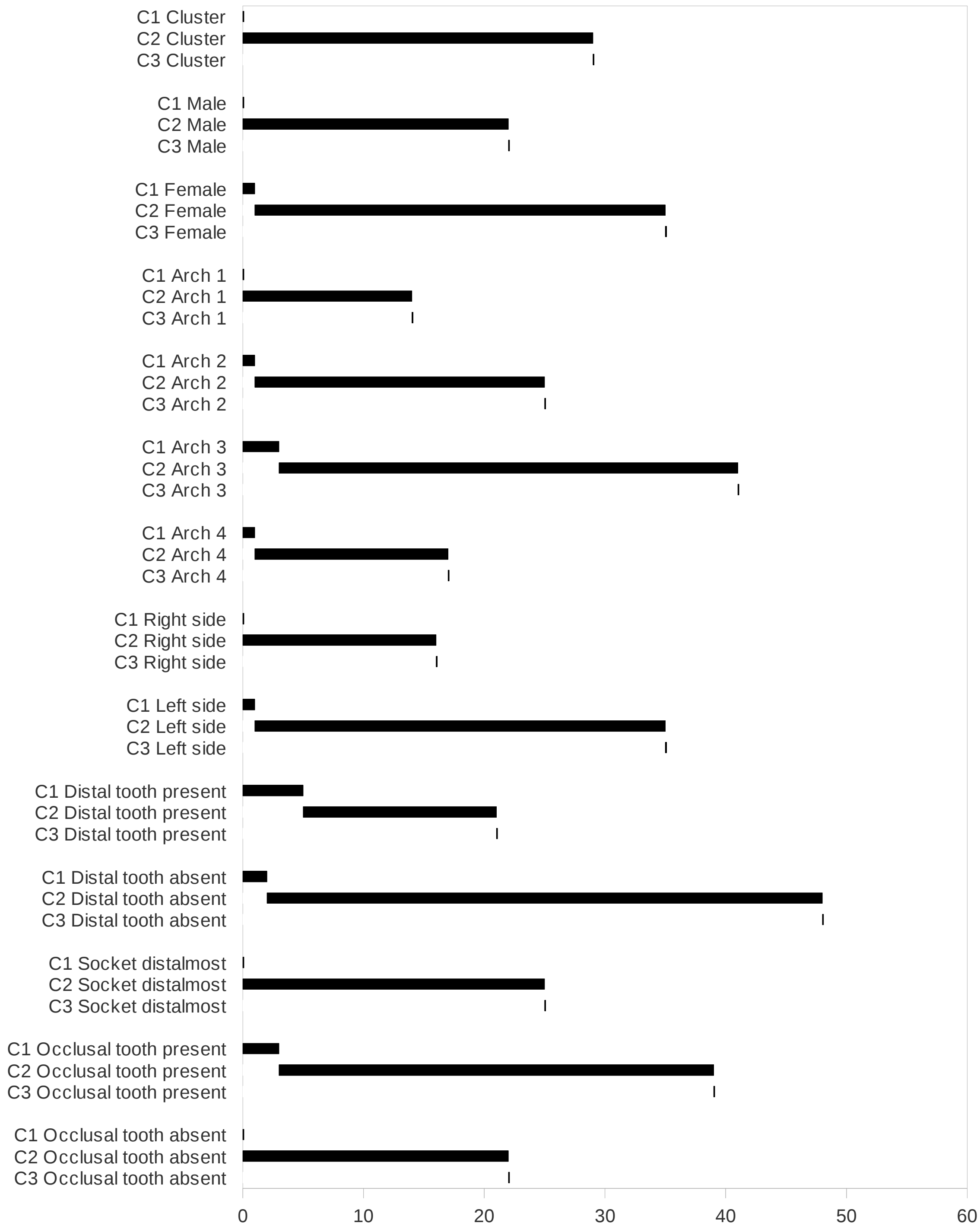


**Figure 5.1.2 Remodeling-centric Healing Timelines of Selected Variables**

Timelines displaying the progression from one cluster to the next (C1, C2, C3) of specific values for each variable which contain significant variation for the second cluster. Ranges are one standard deviation above and below the trimmed average; negative estimates have been amended to 0. The minimum TSL for the first cluster in all values is 0 (or the point of tooth loss); in some cases the minimum TSL for the second cluster is also 0 which means there is no range for the first cluster. There is no maximum TSL for the third cluster.

*Error and reliability*

For some variables significance may be the result of bias due to sample size and distribution; with the exception of such examples however the results are supported by statistically significant independent sample groups. Statistically significant TSL variation indicates in particular that the variation is not the result of a random distribution. Testing on an additional substantial cohort of healing sockets with known TSL would be expected to corroborate these findings. The remodeling-centric schedules offer reliable nonrandom TSL estimates for the osseous-remodeling sockets; a minimum TSL after which sockets can be presumed to be fully remodeled; and a maximum TSL before which sockets can be presumed to lack osseous healing.

## 5.2 Forces and Anatomy

As mastication and other forces have effects on modeling and remodeling rates for general alveolar remodeling they are similarly expected to have effects on that following tooth loss (Shimomoto et al. 2007). This is also a reasonable explanation for the variation between anterior and posterior socket healing times (in Figure 5.2.1): although statistically insignificant this may be due to the extreme dominance of the sample by posterior sockets. A more balanced cohort in this regard could further investigate this possible relationship. Significant variation between sides (in Figure 5.2.2) may be reflective of either physiological lateral asymmetry or behavioral habit (Martinez-Gomis et al. 2009). Neighboring tooth status also has an effect on the rate of osseous healing with mesial and distal tooth absence and occlusal tooth presence considerably delaying remodeling (Figure 5.2.3). As an increase in alveolar pressure increases osseous resorption it may be either that more new bone is required to accommodate this increased resorption or that the rate of remodeling is higher in the early stages of bone development (Hammarström and Lindskog 1985).

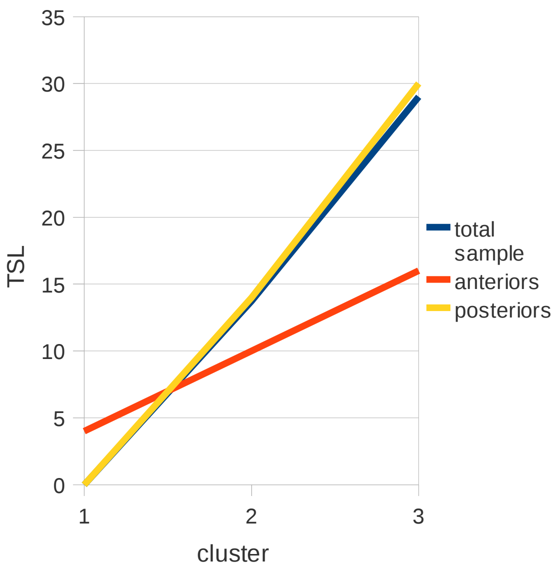


**Figure 5.2.1 Rate of Socket Healing by Site Category 2**
The data are from the trimmed remodeling-centric schedules. The divergence between the times required for sockets from different categories to reach the second cluster are statistically insignificant ($p>0.05$).

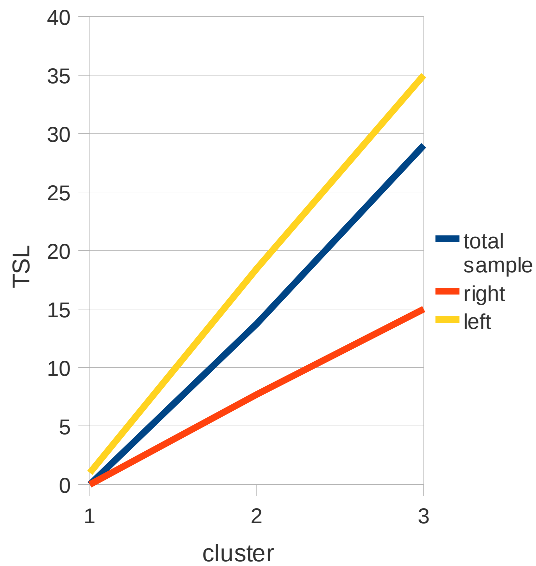


**Figure 5.2.2 Rate of Socket Healing by Side**
The data are from the trimmed remodeling-centric schedules. The divergence between the times required for sockets from different sides to reach the second cluster are statistically significant ($p<0.01$).

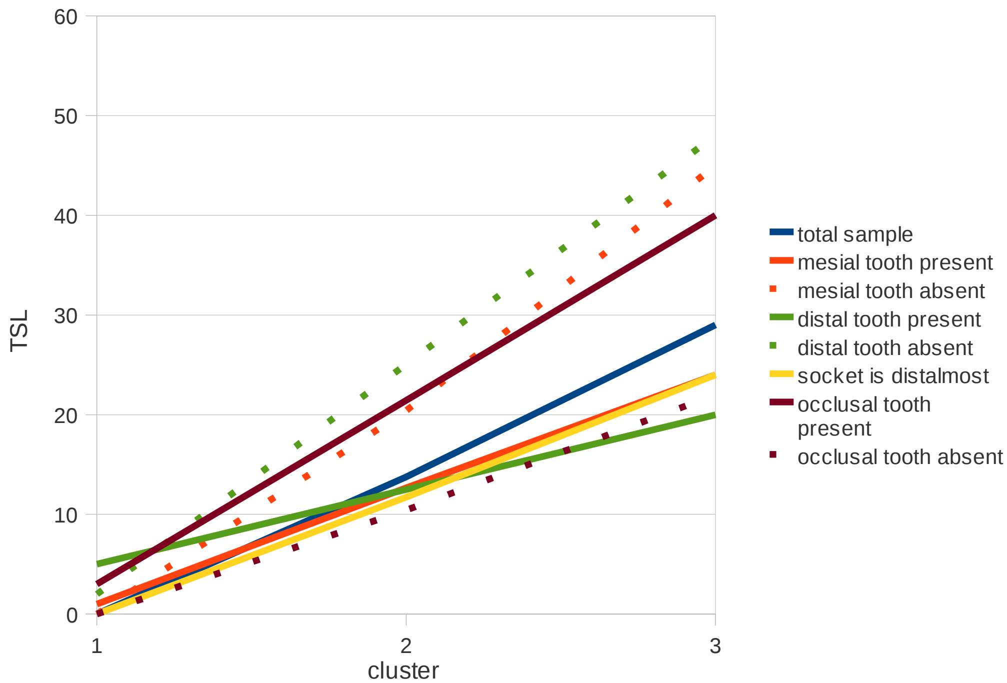


**Figure 5.2.3 Rate of Socket Healing by Neighboring Tooth Status**

The data are from the trimmed remodeling-centric schedules. The divergence between the times required for sockets with different mesial tooth statuses to reach the second cluster are statistically insignificant ($p>0.05$); those for different distal and occlusal tooth statuses are statistically significant ($p<0.05$ and 0.01, respectively).

## 5.3 Practical Application

It has been concluded that a largely remodeling-centric approach (i.e., use of the remodeling-centric data) would be most favorable. This however negates the possibility of using radiolucency stage data as they are not independent from stages of fullness (and therefore cluster assignation). In addition this particular variable may not be suitable for dry bone samples as they rely heavily on soft tissue vascularization and density. Healing time as it is affected by different treatment options as well has little relevance not only for archaeological remains but also for individuals either without access to modern clinical extraction or for whom tooth loss was not the result of extraction although they may be of use for further clinical studies or in clinical practice.

Because phase 2 will test the appearance of socket remodeling in dry bone specimens stages of radiolucency and all treatment variables will be ignored. The remodeling-centric method will be applied and data for the first cluster not utilized. This latter condition is because a socket without osseous healing is identified as resulting from postmortem tooth loss and is simply a consideration of recovered osseous remains. Any variables which have been identified as exhibiting statistically insignificant variation for the second cluster in phase 1 will not be utilized as factors in phase 2.

*Dentistry and implantology*

In combination with the basic data on fullness and related variables the findings on radiolucency contribute to radiographic approaches to bony socket healing. Stage of radiolucency progresses concurrently with stage of fullness although one may not necessarily be determined from the other (Figure 5.4.1). In addition those sockets with a more advanced stage of radiolucency in the third cluster are more likely to have been ossified for a longer period of time; more careful investigation into this possibility may both confirm it and allow for the creation of a post-ossification TSL schedule.

This study now also contributes to an enormous body of research on both systemic and local treatments with regard to healing following exodontia. The significant results in various treatment categories such as the use of analgesics at the time extraction or antibiotics or chlorhexidine rinse at follow-up may be of particular interest in implantology where methods are constantly being tested to encourage rapid sturdy alveolar remodeling prior to implantation. Even without any particular type of treatment being singled out the application of some form of common medication at the time of tooth extraction or follow-up has a positive effect on the time required for a socket to partially remodel.

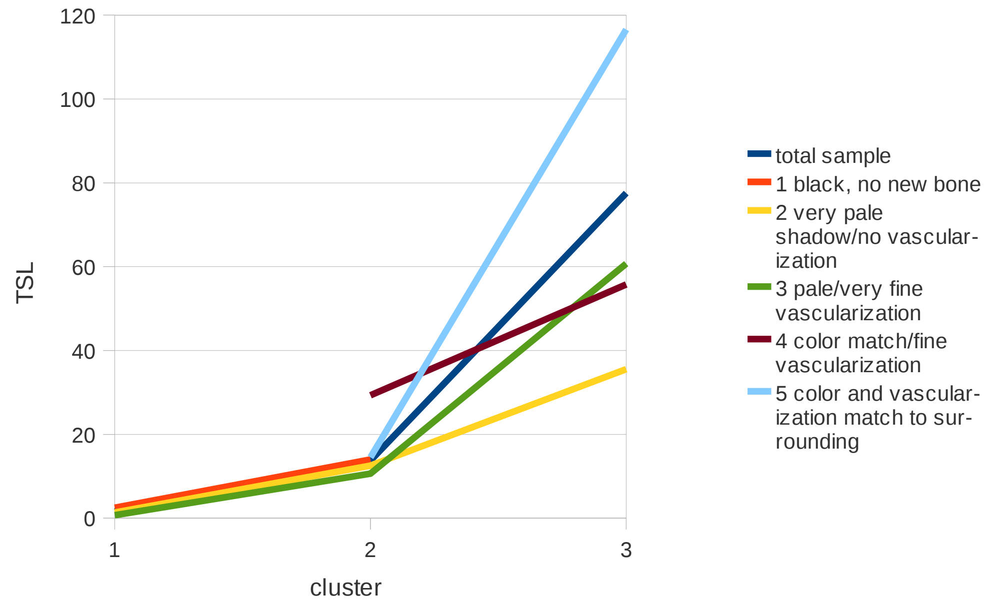


**Figure 5.3.1 Rate of Socket Healing by Stage of Radiolucency**

The data are trimmed averages from the limited-TSL schedules. The divergence between the times required for sockets with different stages of radiolucency to heal to the second and third stages of remodeling are statistically significant ($p<0.05$ and $<0.01$, respectively). No sockets in the first cluster were recorded with radiolucency stages 4 or 5 as no sockets in the third cluster were recorded with stage 1.

Finally application will be reliant on similar limitations as those imposed for data collection. Although these findings may still be utilized as guidelines, exclusion criteria should be applied to the test samples as they were to the original cohort. The full schedules for all variables located in the Appendix may be further utilized in order to provide a very general idea of TSL for each value of each variable with the knowledge that most such variables are insufficiently represented or comprise statistically insignificant TSL variation.

*Osseous remains*

Osseous samples have different limitations from those of clinical samples. As with the clinical data the full (remodeling-centric) schedules for all variables located in the

Appendix may also be further utilized to provide a very general idea of variable influences of TSL but those variables which have little bearing on tooth loss outside of a modern clinical setting – treatment details for example – may be ignored entirely regardless of significance. For all partially or completely skeletonized cases or in forensic circumstances where taphonomic decay is in progress stages of radiolucency *may* be applicable variables but this would depend entirely on the confidence and expertise of the radiography technician and interpreter. Stage of radiolucency may be too dependent on living soft tissue structure and vascularization and so have limited application with necrotized soft tissues or dry bone.

In general the aims outlined in detail in the previous chapters have largely been met: this research has produced a reliable method for estimating the time elapsed since tooth loss based either solely on socket bony fullness or in addition to other grossly apparent variables which have significant effects on the osseous healing process. What is still absent – and which will be remedied in phase 2 – is comprehensive data on appearance in dry bone. As the schedules stand now they may be utilized with dry bone as well as in clinical cases (explicit instructions and limitations follow) but this will be reliant on whether or not variables are utilized; if they are then all observable variables possible, including those which may be derived from phase 2, should be considered to ensure high precision. Application may however be performed using only the TSL values for the relevant cluster.

*Estimation of TSL*

Estimation of TSL based on these findings regardless of field of application is simple. Only those variables which have been shown to be significant for the relevant cluster need be recorded and an average of all TSLs for each recorded applicable value of each variable serves as the estimate. Due to certain variables being applicable to TSL prediction only under certain conditions of fullness, Table 5.3.1 indicates which variables (and values) are to be recorded and utilized for each cluster. Examples of application with the limited-TSL schedules are in Table 5.3.2 and the remodeling-centric schedules in Table 5.3.3; blank forms and reference tables for both are available in the Appendix. In cases where the value for a given variable is unknown or indeterminate then that variable is excluded. As long as a cluster can be identified then it is possible to estimate TSL but an increased pool of variables will increase precision.

*Phase 2*

At the time of this analysis the data for phase 2 had already been collected. Although this is in no way damaging it does mean that considerably more data were collected than were necessary as those variables which were not found to exhibit statistically significant variation (or which lacked sufficient sample sizes) will be disregarded. The remodeling-centric schedules will be employed and variables regarding treatment or stage of radiolucency will be disregarded entirely. Estimations of TSL will then be utilized to test additional variables (largely descriptive of gross appearance) which could not be assessed in phase 1. Due to an inability to identify AMTL without bony socket remodeling data from the first cluster will also not be utilized.

**Table 5.3.1 Variables Utilized in TSL Estimation**

| Cluster 1 | Cluster 2 | Cluster 3 |
|---|---|---|
| Cluster<br>(no osseous development) | Cluster<br>(osseous remodeling up to ¾-full) | Cluster<br>(remodeled, more than ¾-full) |
| *Application of chlorhexidine-containing rinse at follow-up (yes/no)* | Sex<br>(male/female) | Sex<br>(male/female) |
| | Arch<br>(1/2/3/4) | Age<br>(<20/20-50/>50 years) |
| | Side<br>(right/left) | Distal tooth status<br>(present/absent/socket is distalmost) |
| | Distal tooth status<br>(present/absent/socket is distalmost) | Socket interference<br>(none/alveolar defect) |
| | Occlusal tooth status<br>(present/absent) | *Any treatment at time of extraction*<br>*(yes/no)* |
| | Stage of fullness<br>(2/3/4) | *Application of non-chlorhexidine containing antiseptic rinse at time of extraction*<br>*(yes/no)* |
| | *Treatment with antibiotics at follow-up*<br>*(yes/no)* | *Stage of radiolucency*<br>*(4/5)* |

For the limited-TSL schedules each cluster is associated with different variables; for the remodeling-centric schedules only those variables associated with cluster 2 are utilized. Values for each variable are in parentheses. Variables not applicable to archaeological samples have been italicized.

**Table 5.3.2 Examples of Limited-TSL Schedule TSL Estimation**

| Variable | Sample 1 | | Sample 2 | | Sample 3 | | Sample 4 | | Sample 5 | | Sample 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Value | TSL | Value | TSL | Value | TSL | Value | TSL | Value | TSL | Value | TSL |
| Cluster | 1 | 2 | 2 | 14 | 2 | 14 | 2 | 14 | 3 | 78 | 3 | 78 |
| Sex | | | female | 18 | male | 10 | female | 18 | male | 108 | female | 46 |
| Age | | | | | | | | | >50 | 31 | <20 | 52 |
| Arch | | | 1 | 7 | 4 | 9 | 2 | 13 | | | | |
| Side | | | right | 8 | right | 8 | left | 18 | | | | |
| Distal tooth | | | present | 13 | distal-most | 12 | absent | 25 | absent | 111 | present | 69 |
| Occlusal tooth | | | present | 21 | absent | 10 | present | 21 | | | | |
| Interference | | | | | | | | | alveolar defect | 101 | none | 67 |
| Any treatment at the time of extraction? | | | | | | | | | yes | 54 | no | 104 |
| Application of non-chlorhexidine-containing antiseptic rinse at the time of extraction? | | | | | | | | | yes | 86 | no | 43 |
| Stage of fullness | | | 2 | 8 | 3 | 14 | 4 | 20 | | | | |
| Stage of radiolucency | | | | | | | | | 3 | | 5 | 117 |
| Treatment with antibiotics at follow-up? | | | NS | | yes | 17 | no | 9 | | | | |
| Application of chlorhexidine-containing rinse at follow-up? | no | 1 | | | | | | | | | | |
| **TSL Estimate** | | **2** | | **13** | | **12** | | **17** | | **81** | | **72** |

The stage of fullness is equivalent to the sample number (i.e., sample 1 is fullness stage 1, sample 2 fullness stage 2, etc.). Boxes in gray indicate either that the variable or the recorded value for the variable is not included in TSL prediction due to statistically insignificant variation in the original sample. TSLs utilized are listed in full in Table 4.2.4. NS indicates not stated/unknown.

**Table 5.3.3 Examples of Remodeling-centric TSL Estimation**

| Variable | Sample 1 | | Sample 2 | | Sample 3 | | Sample 4 | | Sample 5 | | Sample 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Value** | **TSL** | **Value** | **TSL** | **Value** | **TSL** | **Value** | **TSL** | **Value** | **TSL** | **Value** | **TSL** |
| Cluster | 1 | 0 | 2 | 14 | 2 | 14 | 2 | 14 | 3 | 29 | 3 | 29 |
| Sex | female | 1 | female | 18 | male | 10 | female | 18 | male | 22 | female | 35 |
| Arch | 4 | 1 | 1 | 7 | 4 | 9 | 2 | 13 | 3 | 39 | 1 | 14 |
| Side | right | 0 | right | 8 | right | 8 | left | 18 | left | 35 | right | 16 |
| Distal tooth | present | 5 | present | 13 | distal-most | 12 | absent | 25 | absent | 48 | present | 21 |
| Occlusal tooth | present | 3 | present | 21 | absent | 10 | present | 21 | absent | 22 | absent | 22 |
| Stage of fullness | | | 2 | 8 | 3 | 14 | 4 | 20 | | | | |
| Treatment with antibiotics at follow-up? | no | 0 | NS | | yes | 17 | no | 9 | NS | | yes | 34 |
| **TSL Estimate** | | **1** | | **13** | | **12** | | **17** | | **33** | | **24** |

The stage of fullness is equivalent to the sample number (i.e., sample 1 is fullness stage 1, sample 2 fullness stage 2, etc.). Samples 2-4 and values for Samples 5 and 6 have been reproduced from Table 5.3.2 for reference. Boxes in gray indicate an impossibility (such as scoring a socket as within both first and second clusters). TSLs utilized are listed in full in Table 4.3.1. NS indicates not stated/unknown. Note that the estimates for the first cluster maximums and those for the third cluster are minimums.

# CHAPTER 6 PHASE 2 MATERIALS AND METHODS

In order to make the clinical findings as relevant as possible to osteoarchaeological samples a second experimental phase is in order. While the previous findings assessed the schedule of socket bony modeling in terms of socket fullness the following tests are intended to provide details on the changing gross appearance of a healing socket in dry bone. To this end more elaborate data on mesial and distal ridge resorption and descriptions of the appearance within the socket will be collected and correlations between these and estimated TSL (utilizing the schedules derived from phase 1) will be assessed. The aim of this second phase is to identify the changing appearance of a socket as it heals and fills in with bone and include new variables with significant TSL variation in remodeling-centric estimation.

The methodology for phase 2 relies heavily not only on the full results of the first (for TSL estimation, cluster assignation, and to avoid re-testing variables) but also on the constraints of the material. The nature of dry bone is such that while in some ways it is more restrictive than radiographs of living individuals due to sampling biases or preservation it does allow for the collection of more descriptive data. In particular the severity of four indicators of dental health will be recorded and tested both individually and collectively against TSL to determine their influences on socket healing. The most complete picture possible is inclusive of all variables' processes which progress cumulatively.

Statistical methods employed will be slightly different from those in phase 1 due to the nature of data collected. Clustering is no longer necessary but ANOVAs and linear models will still be employed to assess the significance of estimated TSL variance. Exploratory statistics will also be utilized to assess dataset distributions and the progression of healing of certain variables. In addition relationships between variables other than TSL and cluster/fullness will be assessed with chi-square and Student's *t*-tests in order to determine their independence.

Three archaeological assemblages have been selected for analysis based on overall preservation, size, and accessibility. All will be subjected to the same standards and each represented by uniform data categories and criteria so that each assemblage can be assessed singly or as part of the complete pooled dataset. Because of the inclusion of descriptive data there will also be randomized testing on a small selection of one assemblage in order to assess the significance and factor of intra-observer error. Age and sex have been estimated by multifactorial osteological techniques and divisions thereof are the same as those for the clinical samples. Initial exclusion criteria were based on those of outlined in phase 1 and the limitations of the material.

### 6.1 Sample Selection

Three archaeological skeleton assemblages – Bösfeld, Völklingen, and Barbican – were selected for their generally good individual preservation and completeness, considerable numbers of individuals, and curatorial accessibility. The former two assemblages are from early medieval (Bösfeld) and medieval (Völklingen) Germany and likely to be of a similar genetic background to the individuals from the clinical study: this is important to ensure similar rates of bone modeling and remodeling (although the most significant differences in bone dynamics tend to occur between races). The selection of past populations from similar temporo-spatial regions is the best way to control for any such effects.

Demographic divisions have been organized similarly to those for the clinical data and with the inclusion of an "indeterminate" group for both categories. Exclusion criteria are in some ways similar to those for the clinical data (such as rejection based on an obscured socket) but in most ways are specific to the material. Awareness of most conditions and utilization of modern medications are simply not possible and so exclusionary traits are more often considerations of preservation and much less on possible systemic interference.

*Age and sex divisions*

Both age and sex have been previously estimated by the primary investigator(s) of the respective assemblage. Methodology between them differs slightly but the core techniques are the same. Sex is largely estimated through pelvic and cranial morphology (Buikstra and Ubelaker 1994; Phenice 969; Schwartz 1995) and age with degree of dental attrition, cranial suture closure, and degenerative pubic symphysis and iliac auricular surface changes (Brooks and Suchey 1990; Buckberry and Chamberlain 2002; Lovejoy 1985; Meindl and Lovejoy 1985; Miles 1963). In younger individuals age estimation also takes advantage of dental calcification and eruption as well as bone fusion and metrics (Scheuer and Black 2000). These are reliable standards for sex and age estimation in osteoarchaeology but are dependent upon good preservation and completeness.

As in phase 1, individuals will be divided into three age categories: under 20, 20 to 50, and over 50 years of age. These categories are intentionally broad in order to encapsulate and separate pubertal and post-menopausal samples (see 3.2 above). This will also take advantage of the constraints of current osteological morphological techniques despite a multifactorial approach as age estimations are often ten-year ranges (or greater).

Individuals which lack a designation which falls into one of these groups – such as those with "indeterminate" or "adult" age estimations – will be marked as of indeterminate age and excluded from tests where age is a factor. Individuals with a "juvenile" or "subadult" estimation will be grouped with the <20 individuals. Sex estimation too will consist of "indeterminate" as a third option and these will be excluded from tests where sex is a factor.

*Exclusion criteria*

Ideal exclusion criteria are unfortunately not practical for application to sometimes quite fragmentary osseous remains. Even while accounting that a great many diseases which can greatly affect bone remodeling rates – such as endocrine disorders – are largely if not wholly invisible in past populations, pathological indicators which are visible in osseous remains are subject to the osteological paradox (Wood et al. 1992). Simply put, long-term disease is more likely to be identified than short-term or recent-onset disease although the effects on bone dynamics and remodeling rates may be the same regardless of disease duration. Because of this paradox there is a possibility of excluding individuals on the basis of apparent disease while including individuals which may have been similarly affected but exhibit no pathological indicators. In order to avoid this problem individuals will not been excluded on the basis of systemic illness unless its indicator(s) directly interferes with the bony oral tissues. This hypothetically includes only conditions such as leprosy expressed in the rhinomaxillary region, advanced scorbutic changes to the alveolus, or less common pathologies such as neoplastic disorders.

Exclusion will also occur in some cases on the basis of poor preservation or due to some manifestations of oral pathologies. If the socket is overly fragmentary, obscured, or damaged it will be rejected. An active interfering alveolar defect, but not periodontitis, will also be justification for exclusion. Only one suitable and well-preserved remodeling socket is necessary and the preservation and completeness of the other recovered remains, including dentition and oral elements, is irrelevant. Multiple instances of AMTL and completely edentulous jaws or individuals will not be excluded provided that each individual socket can be identified separately from its fellows.

*Bösfeld*

The Bösfeld assemblage, recovered from a Frankish Merovingian cemetery in Mannheim-Seckenheim in use during the $6^{th}$ and $7^{th}$ centuries, consists of almost a thousand individuals largely from typical single inhumation contexts. Although initially discovered in 1906/7 the site was finally excavated from 2001 to 2004 and the human remains are currently being studied within the confines of several comprehensive anthropological projects particularly with regard to trauma and paleopathology, dental disease, and paleodemography. The assemblage is currently curated by the Institute of Anthropology of the Johannes Gutenberg University in Mainz, Germany, under the authorities of Prof. Dr. Kurt W. Alt and Christian Meyer. Preservation can vary extremely but tends to be medium to good and completeness of the jaws and dentition is usually medium to high. Notable within the population are frequent cases of various dietary deficiencies (e.g. anemia, rickets), occasionally quite severe dental disease (such as inhibitive calculus), and infectious diseases (e.g. treponematoses, pulmonary disease). The rates for these however tend to be average to high-average when compared with local contemporary assemblages.

*Völklingen*

A cemetery from the 14th and 15th centuries in Völklingen, Saarland, has yielded a few hundred individuals with a slightly high proportion of recovered subadults (albeit not beyond that of an attritional paleodemographic profile). It, like Bösfeld, is also a part of ongoing observational and molecular anthropological investigations. The assemblage is currently curated by the Institute of Anthropology of the Johannes Gutenberg University of Mainz, Germany, under the authorities of Prof. Dr. Kurt W. Alt and Petra Held. Preservation varies from poor to excellent but tends to be quite good and completeness of the jaws and dentition is usually high. Although initial investigations indicate not unusual rates of infectious or metabolic diseases, dental disease tends to be both frequent and severe in even young adulthood. Despite the lack of preliminary analyses having been performed on many individuals – at the time of data collection age and sex estimations were available for just over 100 adults – each will be assessed with an aim to inclusion in this study and exclusion will not be dependent upon the availability of other osteological findings (or lack thereof). Where sex or age estimations are not available they will be determined by the author using the methods outlined above.

*Barbican*

The Barbican assemblage was recently recovered (2007-2008) in association with the excavation of All Saints Fishergate Church in York, England. The peak activity of the cemetery is concurrent with the period of use of the church, estimated to have been constructed prior to the Norman invasion in 1066 and to have survived through 1586; almost 600 individuals are from this phase. In addition there are some 113 individuals recovered from ten mass graves thought to be from the 1644 siege of York after the church was partially demolished. These are predominantly 30-40-year-old males suspected to have been military personnel who succumbed to disease rather than battle wounds (as rates of perimortem trauma within this group is low); the paleodemographic profile of these latter burials indicates a catastrophic mortality pattern consistent with infectious disease. The entire assemblage is currently curated by the University of Sheffield's Department of Archaeology in Sheffield, UK, under the authority of Prof. Andrew Chamberlain. Preservation is mostly from good to excellent and jaws and dentition are frequently complete. The individuals are fairly robust and several exhibit pathological indicators of treponematosis, tuberculosis, leprosy, and scurvy.

## 6.2 Observer Error

In order to ensure minimal error, particularly as most data is qualitative rather than quantitative, intra-observer testing will be performed on a limited sample. Following a waiting period of at least a month between data collection phases in order to insure against memorization a small number of sockets will be selected at random from the Bösfeld assemblage. They will be re-recorded in full and tested against the initial data to determine the significance of any differences in the dental health index (PAMTL, periodontal disease, caries, attrition, and calculus) and of all the categories in the remodeling site (neighboring and occlusal tooth presence, interference, fullness, mesial and distal ridge presence, and mesial, distal, buccal, lingual, and apical descriptors). Statistically significant variation between the initial data and subsequent test may result in alterations to descriptions, guidelines, or methodology in the relevant category.

## 6.3 Statistical Analyses

Due to the nature of the data collected and the results desired several types of statistical methods must be utilized. The primary difference between the analytical methods used for phases 1 and 2 is that here cluster analysis is not necessary and now the focus is solely on variables aside from fullness. Descriptive statistics will be utilized in a similar manner as in phase 1 as will ANOVAs and linear models. Initially however variables will be tested against one another in order to determine their dependence upon or independence from other variables. Relationships will be assessed mostly with Student's *t*-tests but Chi-square tests will be employed where units differ and to assess relationships with specific values of specific variables. These results will ensure that variables which are have significant relationships will not be treated as independent from one another and may provide insight into the relationships between certain variables, bony socket healing, and mastication force dynamics. Observer reproducibility (and error) will also be tested with Student's *t*-tests. All tests will be performed by the author using Open Office or the SPSS 15.0 statistics package. Should weighting be deemed statistically necessary it will be undertaken by proportionally increasing the underrepresented sample group(s).

*Descriptive statistics*

Descriptive statistics will be again be applied in many forms at different stages of the data analysis. As in phase 1 graphs of various data distributions will provide an understanding of the raw data and indicate skewness. Individual variables will be plotted against TSL values to visualize any apparent influence on the normal rate of socket healing, and multiple variables will be plotted against one another to initially assess relationships.

*Student's* t*-tests*

Each of the five descriptors – the appearance of the mesial, distal, buccal, lingual, and apical regions within the socket – will be scored on an arbitrary nonconsecutive numeric scale (e.g., “2” may not necessarily be expressed after “1”: the numbers are only for ease of differentiation). Student's *t*-tests will compare each region with the others (for a total of ten tests) to determine their independence; a significant result would indicate that the two descriptors are not independent of one another but the link between them will not be clear. The relationship between mesial and distal interdental ridge presence will also be assessed in this way, as will ridge status with the respective neighboring tooth status. A significant result in these tests would again indicate a nonrandom relationship between the presence or absence of the ridges or of the ridges and the respective neighboring tooth. Finally observer error will also be assessed with Student's *t*-tests which will compare the initial and subsequent data collected for significant divergence. A significant result from this test may indicate observer error is responsible for actual results and may cast considerable doubt on all results.

*Chi-square*

Chi-square tests assess the significance of actual frequencies to expected frequencies. They will here be employed to test inter-variable significance where the units of measurement differ: the expected frequencies will be ratios of the total dataset and the actual frequencies ratios of a limited dataset restricted to one or more values of one or more variables. Significance between the actual and expected results indicates a relationship between the variable tested and the value(s) of the variable(s) used to restrict the actual frequency cohort. Tests will be performed with mesial and distal descriptors and their respective relationships with neighboring tooth and ridge presence and absence.

*ANOVAs and linear models*

One-way ANOVAs will be performed as in phase 1 for each variable for both clusters to assess the significance of inter-variable TSL value variation. General linear models will be created as in phase 1 for variables unique to phase 2.

## 6.4 Testing

Data were collected by the author on site at the Institute of Anthropology of the Johannes Gutenberg University in Mainz (Bösfeld and Völklingen) and at the Archaeology Department of the University of Sheffield (Barbican) between November 2009 and December 2010. The previously established methodology was followed with minor ad hoc changes. Occasional low magnification (no more than 4x) and directed light were employed to aid observation. No imaging or invasive techniques were employed. Each available individual from the three assemblages – a total of approximately 2000 individuals – were initially assessed in order to determine their suitability for this project; with the exception of 20 sockets from ten randomly selected individuals assessed for observer error each socket was observed and recorded only once. Individuals were rejected due to a lack of AMTL or an overly fragmentary and incomplete dentition. They were not rejected due to number of recovered teeth, or if only one jaw was observable, or if only the dentition and alveolar fragments were recovered. The sockets of those individuals which met these criteria were then assessed in terms of their suitability and rejected if they were obscured or damaged. In some cases substantial local alveolar defects excluded the related socket(s) from consideration. Provided there was at least one observable socket for an individual they were then fully assessed.

Problems encountered were almost exclusively due to poor preservation and completeness. In many cases several teeth were lost antemortem but not all of the sockets could be recorded due to postmortem damage. Several individuals were also missing considerable segments of dental arches or even entire jaws; this had perhaps the most significant bearing on the dental health index which was not calculated in such instances. In addition there is some concern for significant interference by disease at most of the sites. Although initially it was hoped that there would be sufficient samples free of pathological indicators to be able to treat affected sites separately or even exclude them altogether it was quickly realized that this would not be possible. The only real change from the transferable methodology employed in phase 1 was to grade fullness in thirds rather than quarters. The final fullness grades then fell into a four-point scale (in Figure 6.4.1): (1) apex to 1/3-filled; (2) 1/3-filled to 2/3-filled; (3) 2/3-filled to filled but depression visible; (4) completely filled, level or convexly ridged alveolus. This was due to difficulties in distinguishing between quarters as was done with the radiographic samples and it was only due to experience with human dental remains that fullness was at all able to be estimated by the author and principal investigator as there is no possibility of general comparison with neighboring tooth root depth.[11] As data were collected before cluster assignation was possible conversion is slightly off with the new fullness stages, but the first and second of these have been assigned to the second cluster with the latter two assigned to the third cluster.

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[11] Metrics were disregarded as a way to maintain the quarter-scale as tooth root length is not easily and precisely estimated.

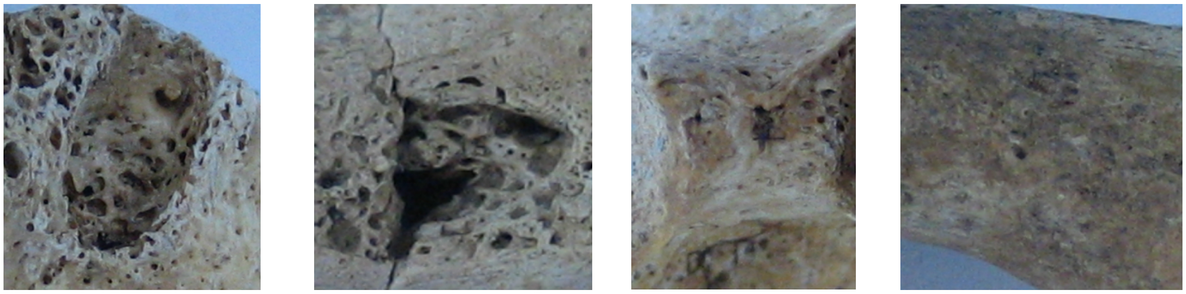

**Figure 6.4.1 Phase 2 Data Collection: Stages of Fullness**
Note the first stage is not for a complete lack of bone formation, because in such cases the socket would be deemed as resulting from postmortem tooth loss rather than antemortem. From left to right: stage 1, new bone formation at apex to socket 1/3-filled; stage 2, socket 1/3- to 2/3-filled; stage 3, socket 2/3-filled to full but with a depression still present; stage 4, socket completely filled with level alveolus.

*Dental health*

Dental health will be assessed through the standards outlined by the dental health index – a system designed by the author to classify entire dentitions on their most severe pathological indicators.[12] Essentially it considers those indicators which are representative of dental health and scores them on a scale of 1 (healthy) to 4 (severe pathology); an increased score is indicative of a greater chance of tooth loss. The index is the average of the most severe score in the entire dentition for each indicator, of which there are five: number of previously lost teeth due to pathology (PAMTL); severity and type of periodontal disease; severity of caries; intensity of attritional wear; and type of calculus accumulation.[13] The details for each stage of each indicator are outlined in Table 6.4.1 and photographs of examples have been provided in Figures 6.4.2-5.

Note that although the index is intended for application to archaeological remains – and it will be utilized in phase 2 of the experiment – only dental disease indicators will be scored

[12] Although publication of the index is intended the article is still in the final stages of preparation and has not yet been accepted by a journal.

[13] Dental hypoplasia, often considered an indicator of dental health, is actually one of systemic stress during development. In addition although attrition is technically mechanical rather than pathological it will eventually expose the pulp cavity if it occurs faster than secondary dentin can be produced and in such a case the sequelae are often the same as for caries: pulpitis, alveolar osteomyelitis, and a high likelihood of pathological tooth loss.

in this first phase. Calculation of the index however is expected to be problematic at times in clinical application with considerations of written differentiation between calculus and plaque, a definition of what constitutes PAMTL, and low levels of attrition among others. If it is possible to calculate an index for a substantial portion of the cohort then it will be applied as an additional variable, but if not then this will be a feature of phase 2 only. Although there are various similar indices intended for use in clinical studies, they would be of little use in archaeological samples where restorations, soft tissue changes, and pain are unknown (Burke and Wilson 1995; Marcus et al. 1980). By using applicable factors included in the dental health index on a case-by-case basis in phase 1 any results will be immediately relevant to the phase 2 sample.

**Table 6.4.1 Dental Health Index Scoring Standards**

| Score | PAMTL | Periodontal disease | Caries | Attrition | Calculus |
|---|---|---|---|---|---|
| **1 none/healthy** *no risk of PAMTL* | 0 (teeth) | Healthy alveolus, no porosity | None | None or only enamel facets | None |
| **2 mild** *low risk of PAMTL* | 1 | Mild periodontitis: porous crest with slight resorption; residual interdental crests maintained; no guttering | Defect within or stain on enamel or cementum | Wear exposes dentin | Supragingival accumulation |
| **3 moderate** *increased likelihood of eventual PAMTL* | 2-3 | Severe periodontitis: porous crest with complete resorption of interdental crests and/or presence of guttering | Defect within or exposing dentin | N/A | Subgingival accumulation |
| **4 severe** *PAMTL very likely in the near future* | ≥4 | Alveolar osteomyelitis: any alveolar defect not of crestal origin (includes furcal and apical defects, abscesses, and granulomas) | Defect exposes or penetrates the pulp cavity | Wear exposes pulp cavity | N/A |

The dental health index was derived by the author in order to broadly estimate dental health in archaeological human remains. It is based on periodontal disease, caries, attrition, and calculus as indicators with a high correlation to pathological antemortem tooth loss (PAMTL). The standardization of terminology and stage of severity for each of these indicators was thus required and is outlined here in full.

**Figure 6.4.2 Dental Health Index Scoring Standards: Periodontal Disease**
From left to right: none, healthy alveolus; mild, mild periodontitis; moderate, severe periodontitis; severe, alveolar osteomyelitis.

**Figure 6.4.3 Dental Health Index Scoring Standards: Caries**
From left to right: healthy, no caries; mild, caries stain on enamel; moderate, caries penetrates dentin; severe, caries infiltrates pulp cavity.

**Figure 6.4.4 Dental Health Index Scoring Standards: Attrition**
From left to right: healthy, enamel facets; mild, wear exposes dentin; severe, wear exposes pulp cavity (including subsequent pulp destruction).

**Figure 6.4.5 Dental Health Index Scoring Standards: Calculus**
From left to right: healthy, no accumulation; mild, supragingival accumulation; moderate, subgingival accumulation.

*Data collected*

General individual data consisted of an identification number (for differentiation and in order to perform inter- and intra-observer tests) along with age and sex estimations. A basic dental inventory differentiated between presence, ante- and postmortem absence, and apparent noneruption/impaction/agenesis for each tooth. Dental health was assessed by the standards for the dental health index outlined above. Socket-specific data consisted of fullness, socket interference, mesial and distal ridge status, and description codes of the internal mesial, distal, buccal, lingual, and apical surfaces of the socket. Data manipulation then also noted if the teeth distal, mesial, and occlusal of the modeling socket were present or absent at the time of death. In all socket categories indeterminate or not available were also options and this was frequently recorded where neighboring dentition and bony structures were damaged or not recovered. Each socket comprised a single sample consisting of 53 points. Because the data were recorded prior to analysis of the phase 1 data, substantially more information was collected than was necessary; not all of the data were utilized. The form utilized has been reproduced in Table 6.4.2 and photographs of examples of the individual descriptor values have been provided for reference in Figure 6.4.6.

**Table 6.4.2 Phase 2 Data Collection Form**

*individual and general data*

| ID | Sex | Age category | Dental Health Index Scores | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | PAMTL | Periodontal disease | Caries | Attrition | Calculus | DHI |
| Bösfeld 840 | F | 2 | 3 | 3 | 3 | 2 | 3 | **3** |
| | | 1 <20 | from dental health index | | | | | |
| | | 2 20-50 | | | | | | |
| | | 3 >50 | | | | | | |

*dental inventory*

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9 | 9 |
| **18** | **17** | **16** | **15** | **14** | **13** | **12** | **11** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** |
| **48** | **47** | **46** | **45** | **44** | **43** | **42** | **41** | **31** | **32** | **33** | **34** | **35** | **36** | **37** | **38** |
| 0 | 1 | 2 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 0 |

| | |
|---|---|
| 0 | unerupted/impacted/agenetic |
| 1 | present |
| 2 | AMTL |
| 3 | PMTL |
| 4 | deciduous tooth retained |

*site details*

| Site | Neighboring teeth | | | Interference | Fullness | Ridges | |
|---|---|---|---|---|---|---|---|
| | Occlusal | Mesial | Distal | | | Mesial | Distal |
| 46 | 1 | 1 | 1 | 0 | 4 | 1 | 1 |
| tooth | 1 present | | | 0 none | 1 apex – 1/3 full (cluster 2) | 1 present | |
| | 2 absent | | | 1 mild periodontitis | | 2 absent | |
| | 9 unknown | | | | 2 1/3 - 2/3 full (cluster 2) | 3 3rd molar (distal only) | |
| | | | | 2 severe periodontitis | 3 2/3 full – depression (cluster 3) | | |
| | | | | 3 alveolar defect | | | |
| | | | | 4 alveolar fracture | 4 depression – level alveolus (cluster 3) | | |
| | | | | 5 jaw fracture | | | |

**Table 6.4.2 continued on next page**

**Table 6.4.2 (continued from previous page)**
*site details (cont.)*

| Descriptors | | | | |
|---|---|---|---|---|
| **Mesial** | **Distal** | **Buccal** | **Lingual** | **Apical** |
| 2 | 2 | 4 | 4 | 1 |
| 1 microporosity | | | | |
| 2 macroporosity | | | | |
| 3 billowed bone | | | | |
| 4 woven bone | | | | |
| 5 bridging | | | | |
| 6 dense bone | | | | |
| 7 smooth lamellar bone | | | | |

A reproduced version edited for formatting purposes of the data collection form utilized for the archaeological study. Codes and necessary descriptions are noted and an example is in gray.


**Figure 6.4.6 Phase 2 Data Collection: Internal Socket Descriptors**
Descriptor is based on the *predominant* appearance in the specific sector. From left to right, top row: socket divisions; microporosity; macroporosity; billowed bone. Bottom row: woven bone; bridging; dense bone; smooth lamellar bone.

# CHAPTER 7 PHASE 2 RESULTS

Data collection and analysis techniques were, for the most part, successful. Data analysis was performed following all data collection on the total cohort (comprising 764 sockets). Considerable imbalances exist throughout the data however: for example only 45 sockets were designated remodeling (cluster 2) whereas 719 were designated ossified (cluster 3). When divided by age category there are more than six times as many sockets from individuals aged 20-50 years (at death) than from those over 50 and only three sockets were recorded in individuals under the age of 20. The data are also skewed in favor of males and the Bösfeld assemblage as well as towards mandibular molars and away from anterior sockets.

Relationships between variables and TSL estimates (derived utilizing the results from the previous experiment) were tested with ANOVAs and ridge status and buccal, lingual, and apical descriptors were found to exhibit significant TSL variation and have been added to the comprehensive estimation form located in the Appendix. In addition it was found that descriptor values diverge from one another as the socket heals and that ridge status was not affected by neighboring tooth status. Assessment of intra-observer error was found to be insignificant, indicating minimal interference with data collection.

## 7.1 Data Distributions

Data were collected on a total of 764 healing sockets from 219 individuals. Each individual was linked with at least one socket; the largest number of sockets recorded for a single individual was 20 but the average was 3.5. Each of the three age categories were represented in the entire sample but this was not the case when the cohort was divided by assemblage: only three individuals under the age of 20 were present in the sample (one male and one female from Barbican and one individual of indeterminate sex from Bösfeld) and the Völklingen sample consists solely of individuals who died between the ages of 20 and 50 (with the exception of one individual of indeterminate age). Both males and females were present in all populations and most age categories of all assemblages. The socket data is very skewed in the direction of individuals who died between the ages of 20 and 50 (83% of the cohort). Approximately 1.7 sockets were recorded from males for each socket from a female. Age category and sex distributions for the cohort are outlined in Table 7.1.1 and displayed in Figures 7.1.1 and 7.1.2, respectively. The sample distribution is fairly skewed in two directions in particular: assemblage (82% of sockets are from Bösfeld individuals) and age (as it is not uncommon for individuals from these period and locations to die before the age of 50 but tooth loss only rarely occurs before the age of 20).

Each socket location is represented with up to 137 samples with an average of 23.9 – far from an ideally distributed sample (Figure 7.1.3). Canine sockets are the worst represented but the combined samples from anterior sites are dwarfed by those from the posterior dentition (Table 7.1.2). Assessment of the cohort as a whole will be dominated by mandibular (76% of the cohort) and molar sites (79%) (Figure 7.1.4). This is largely due to generally good preservation and a high rate of recovery of the mandible as well as a high susceptibility of molars to caries due to enamel topography and eruption times. Distribution by side however is close to even (54% of sockets are from the right side).

**Table 7.1.1 Socket Distribution by Assemblage, Age Category, and Sex**

| | Male | Female | Indet sex | Total |
|---|---|---|---|---|
| Bösfeld <20 | 0 | 0 | 1 | **1** |
| Bösfeld 20-50 | 302 | 196 | 31 | **529** |
| Bösfeld >20 | 59 | 20 | 11 | **90** |
| Bösfeld indet age | 0 | 0 | 5 | **5** |
| **Bösfeld total** | **361** | **216** | **48** | **625** |
| Völklingen <20 | 0 | 0 | 0 | **0** |
| Völklingen 20-50 | 31 | 24 | 0 | **55** |
| Völklingen >50 | 0 | 0 | 0 | **0** |
| Völklingen indet age | 0 | 0 | 4 | **4** |
| **Völklingen total** | **31** | **24** | **4** | **59** |
| Barbican <20 | 1 | 1 | 0 | **2** |
| Barbican 20-50 | 36 | 17 | 0 | **53** |
| Barbican >50 | 16 | 1 | 1 | **18** |
| Barbican indet age | 2 | 0 | 5 | **7** |
| **Barbican total** | **55** | **19** | **6** | **80** |
| All >20 | 1 | 1 | 1 | **3** |
| All 20-50 | 369 | 237 | 31 | **637** |
| All >50 | 75 | 21 | 12 | **108** |
| All indet age | 2 | 0 | 14 | **16** |
| **All total** | **447** | **259** | **58** | **764** |

Distributions of recorded sockets by assemblage and the individual's sex and age category (at time of death).

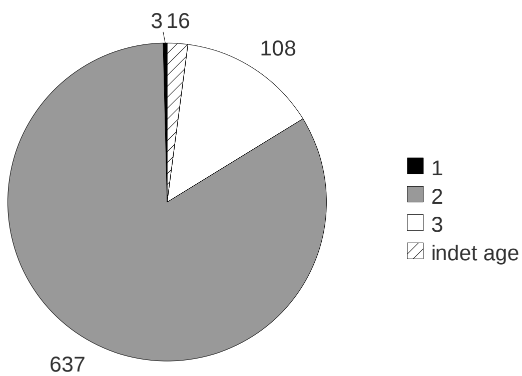


**Figure 7.1.1 Socket Distribution by Age Category**
Distribution of recorded sockets by individual age at the time of death. Sockets recorded from those individuals who died before the age of 20 are in black, from those who died between 20 and 50 in gray, and from those who died after 50 in white. Sockets from those individuals for whom age estimations were not possible are in hatching. All assemblages.

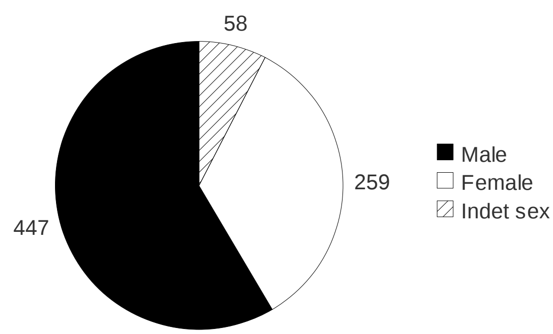


**Figure 7.1.2 Socket Distribution by Sex**
Distribution of recorded sockets by individual sex; all assemblages.

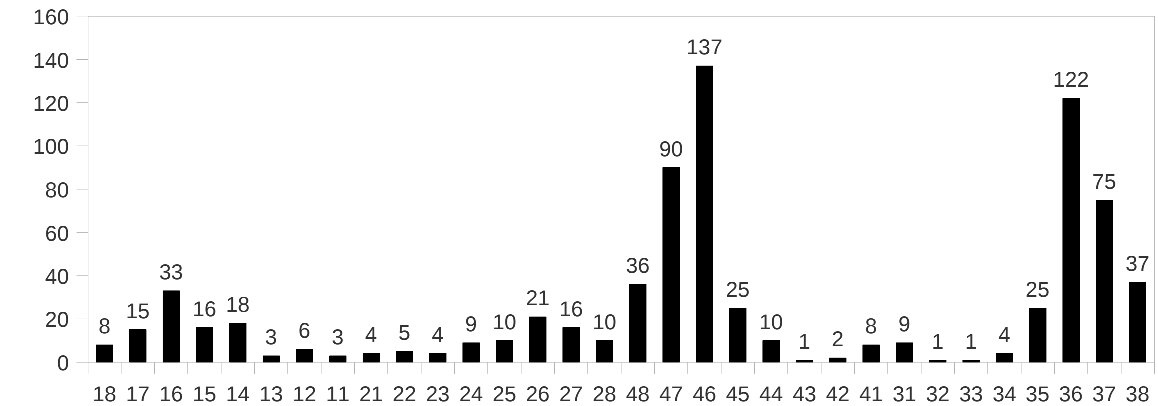


**Figure 7.1.3 Socket Distribution by Site**
A visual depiction of the distribution of recorded sockets by tooth site.

**Table 7.1.2 Socket Distribution by Site**

<table>
<tr><th></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>Total</th><th>Jaw</th></tr>
<tr><td>Arch 1</td><td>3</td><td>6</td><td>3</td><td>18</td><td>16</td><td>33</td><td>15</td><td>8</td><td>102</td><td rowspan="2">181</td></tr>
<tr><td>Arch 2</td><td>4</td><td>5</td><td>4</td><td>9</td><td>10</td><td>21</td><td>16</td><td>10</td><td>79</td></tr>
<tr><td>Arch 3</td><td>9</td><td>1</td><td>1</td><td>4</td><td>25</td><td>122</td><td>75</td><td>37</td><td>274</td><td rowspan="2">583</td></tr>
<tr><td>Arch 4</td><td>8</td><td>2</td><td>1</td><td>10</td><td>25</td><td>137</td><td>90</td><td>36</td><td>309</td></tr>
<tr><td>Total</td><td>24</td><td>14</td><td>9</td><td>41</td><td>76</td><td>313</td><td>196</td><td>91</td><td>764</td><td></td></tr>
<tr><td>Type 1</td><td colspan="2">38</td><td>9</td><td colspan="2">117</td><td colspan="3">600</td><td>Rights</td><td>411</td></tr>
<tr><td>Type 2</td><td colspan="3">47</td><td colspan="5">717</td><td>Lefts</td><td>353</td></tr>
</table>

Distributions of recorded sockets by tooth site. Seven different categorizations – site (e.g. 11, 12), site number (e.g. 1, 2), arch number (e.g. arch 1, arch 2), jaw (mandible, maxillae), side (right, left), group type 1 (incisors, canines, premolars, molars) and group type 2 (anterior, posterior) – may be utilized in statistical analyses in order to identify any differences in healing rates between sites with regard to normal mastication forces.

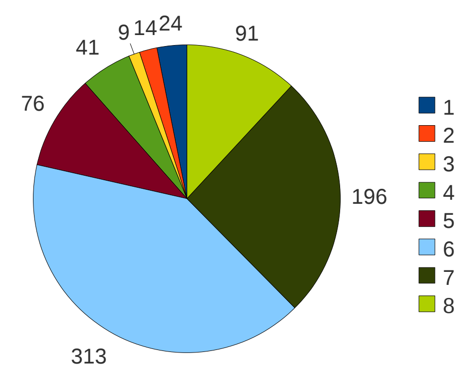


**Figure 7.1.4 Socket Distribution by Site Number**
Distributions of recorded sockets by site number irrespective of arch.

Fullness score distribution within the entire cohort is overwhelmed by the more complete stages – the third cluster (composed of fullness stages 3 and 4) comprises some 94% of samples (Figure 7.1.5). This can be attributed to the cumulative nature of AMTL and the short time required for a socket to fully remodel relative to life span following tooth loss. Because it was not possible to exclude sockets if the tooth was lost more than five years prior to death (the equivalent of what was performed with the clinical test) because TSL was not initially known, this dominance was expected.

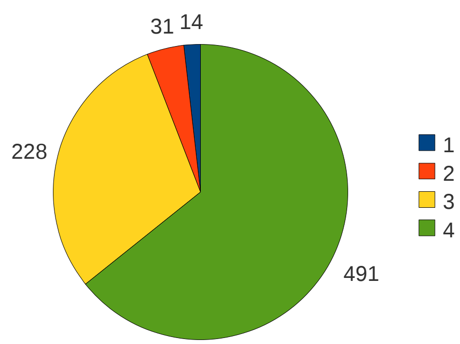


**Figure 7.1.5 Distribution of Socket Fullness Scores**
Stage 1 new bone formation at apex to socket 1/3-filled; stage 2 socket 1/3- to 2/3-filled; stage 3 socket 2/3-filled to full but with a depression still present; stage 4 socket completely filled, alveolus level.

## 7.2 Statistical Analyses

More elaborate statistical tests were performed in order to understand the relationship with TSL values, estimate the significance of variability of TSL values, and provide reliable TSL estimates for the second and third cluster for all new variables. Much of this mirrored the methodology applied in phase 1: relationships were assessed through the use of ANOVAs, general linear models, and averages. Cluster was assigned based on fullness (stages 1 and 2 in this case were designated cluster 2 and stages 3 and 4 designated cluster 3) and TSL estimated utilizing the significant remodeling-centric trimmed TSL schedules from Table 4.3.1. In addition relationships between variables regardless of cluster or fullness, or where this is controlled, were also assessed with the use of Student's *t*-tests and chi-square.

Those variables assessed in this phase with regard to TSL are those which were not observable in phase 1: DHI, mesial and distal ridge status, and mesial, distal, buccal, lingual, and apical descriptors. Other tests included an investigation into the relationships between ridge and neighboring tooth status (insignificant) and those between ridge or neighboring tooth statuses with the respective descriptor (insignificant in most cases). In terms of inter-descriptor relationships it was determined that mesial, distal, and apical descriptors are largely interchangeable, as are buccal and lingual descriptors, but the variation among all of these is initially minor and diverges more as fullness progresses.

For TSL estimation the only addition to the second cluster is of distal ridge status, although insufficient samples for the value of present mean this is not as comprehensive as would be desired. For the third cluster the inclusion of mesial and distal ridge status as well as buccal, lingual, and apical descriptors is supported.

*Inter-variable relationships*

Inter-variable relationships were investigated in order to assess their independence: this is indicated by a significant result by Student's *t*-tests and/or chi-square. An insignificant relationship between some variables may indicate their interchangeability. In all of these tests only those sites which had recorded data in the relevant categories were assessed: any sample scored as “indeterminate” in the relevant variables was excluded.

Chi-square tests assessed potential relationships between descriptor value and neighboring tooth or ridge status. (Mesial descriptors were assessed with either mesial tooth or mesial ridge status; distal with distal; and apical with occlusal tooth status.) The expected distributions were frequency ratios of each value of the selected descriptor in the entire cohort and actual distributions were frequency ratios of each value of the selected descriptor in a smaller cohort limited to one value of the other variables tested (such as mesial tooth absence). Frequency ratios were utilized instead of frequency itself in order to control for sample size. The results are in Table 7.2.1. Both mesial and distal descriptor value distributions were insignificantly associated with those of the distributions for either ridge presence or absence (respectively). It is apparent from Figures 7.2.1 and 7.2.2 that the distribution divergence from the entire cohort for either of these conditions is minor. The same is true for mesial descriptor and tooth status (Figure 7.2.3); distally however tooth presence has a significant relationship with descriptor value distribution ($p<0.01$) and tooth absence is only barely insignificant ($p=0.05$) (Figure 7.2.4). Apical descriptor value distribution was insignificantly associated with those of the distributions for either occlusal tooth presence or absence (Figure 7.2.5).

**Table 7.2.1 Relationships between Descriptors and Tooth and Ridge Statuses**

| | **Descriptor** | | |
|---|---|---|---|
| | **Mesial** | **Distal** | **Apical** |
| **Ridge present** | insignificant | insignificant | |
| **Ridge absent** | insignificant | insignificant | |
| **Tooth present** | insignificant | p<0.01 | insignificant |
| **Tooth absent** | insignificant | insignificant* | insignificant |
| **Site distalmost** | | insignificant | |

Significance of chi-square tests on mesial, distal, and apical descriptor distributions within the entire cohort against cohorts those limited by respective ridge and tooth status. The mesial descriptor was tested with mesial ridge and tooth; distal with distal; and apical with occlusal tooth. Distalmost teeth are third molars except where the third molar is agenetic; these sockets were not included in other cohorts. Variation is insignificant where $p>0.05$. *This test was borderline ($p=0.05$).

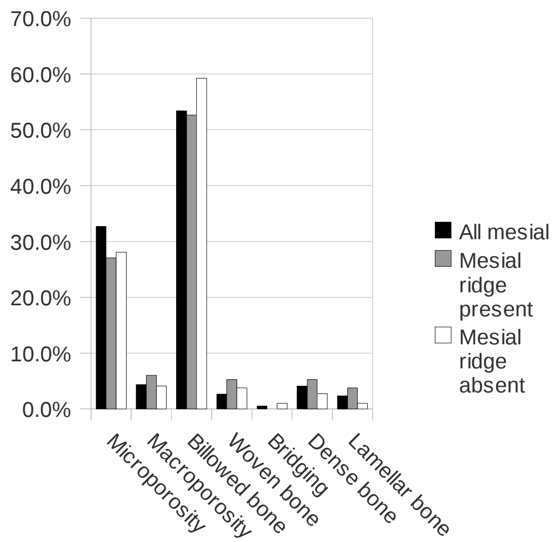


**Figure 7.2.1 Mesial Descriptors and Mesial Ridge Status**

Distribution of sockets with a recorded mesial ridge status by mesial descriptor. Relationships are insignificant.

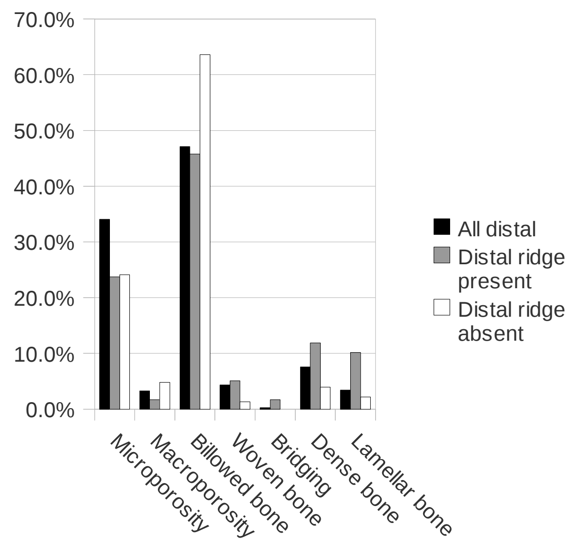


**Figure 7.2.2 Distal Descriptors and Distal Ridge Status**

Distribution of sockets with a recorded distal ridge status by distal descriptor. Does not include distalmost sockets. Relationships are insignificant.

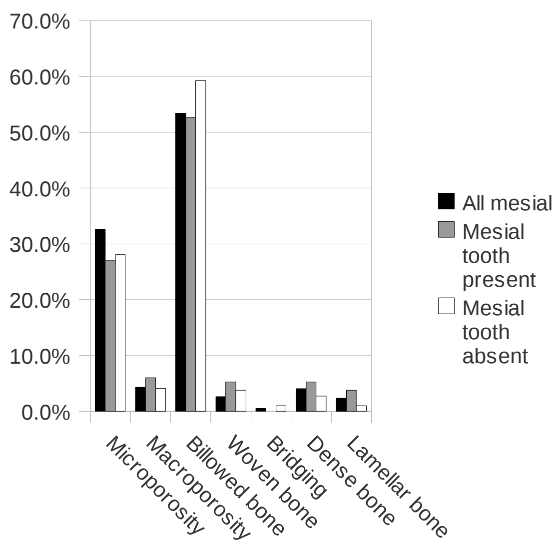


**Figure 7.2.3 Mesial Descriptors and Mesial Tooth Status**

Distribution of sockets with a recorded mesial tooth status by mesial descriptor. Relationships are insignificant.

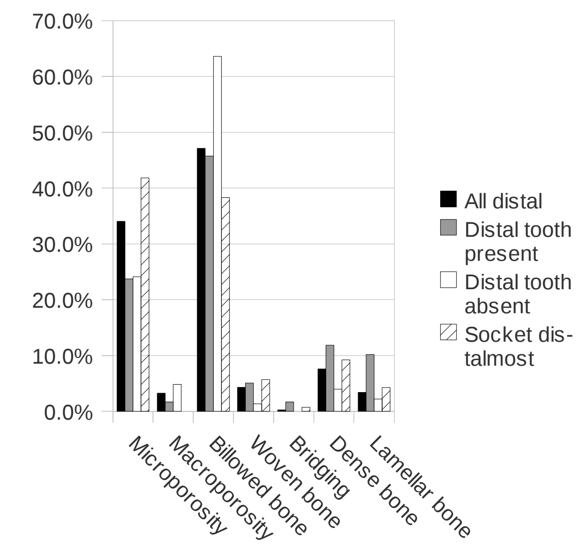


**Figure 7.2.4 Distal Descriptors and Distal Tooth Status**

Distribution of sockets with a recorded distal tooth status by distal descriptor. Distalmost sockets were tested separately from those with an absent distal tooth and both of these have insignificant relationships with descriptor distribution. Distal tooth presence however has a significant relationship with descriptor distribution ($p<0.01$).

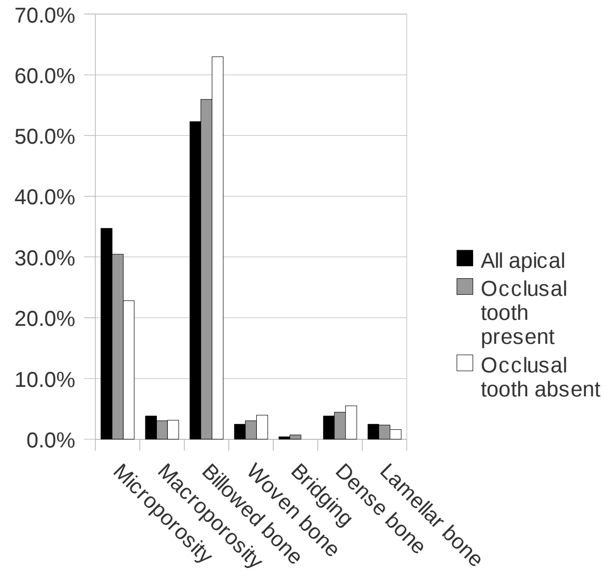


**Figure 7.2.5 Apical Descriptors and Occlusal Tooth Status**
Distribution of sockets with a recorded occlusal tooth status by apical descriptor. Relationships are insignificant.

In addition mesial and distal ridge statuses were assessed with Student's *t*-tests where the site was not naturally distalmost. These criteria were met by 200 sockets and the insignificant result indicates that mesial and distal ridge tend to resorb concurrently. Because ridge resorption can be an indicator of periodontal disease the tests were run again with sites unaffected by pathological interference; these criteria were met by only 59 sockets but the result was again insignificant. When the ratio was investigated it was determined that distributions of ridge absence for both mesial and distal ridges of this latter sample were identical, making the visualization of the statistical insignificance quite clear (Figure 7.2.6). (Note that this was not assessed with regard to age, another potential cause of socket resorption).

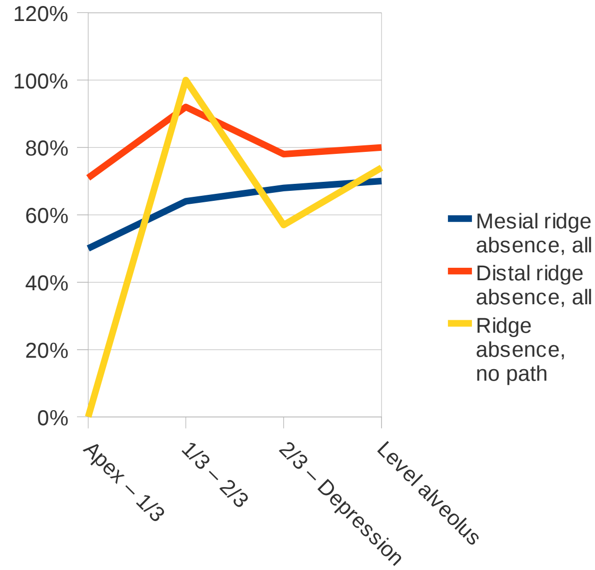


**Figure 7.2.6 Mesial and Distal Ridge Resorption with Increasing Fullness**
Mesial and distal interdental ridge absence distributions by stage of fullness in the entire cohort (blue and red) and in a sample limited to sockets with no related indicators of pathology (yellow). The frequencies of sockets with mesial and/or distal ridge absence in this latter sample were identical and the more erratic nature of the line in the first two stages of fullness is attributed to very low samples for these categories.

Student's *t*-tests were again utilized in order to assess relationships between all descriptors within the entire sample. The pattern of insignificant results, in Table 7.2.2, suggest that the appearance of the bone in mesial, distal, and apical sections of the socket do not need to be distinguished between; the same is true for the buccal and lingual sections. These results indicate that it is only necessary to record a value for each of these two groups (mesial-distal-apical and buccal-lingual) instead of for each of the five separate sections. This is apparent in Figure 7.2.7, the primary differentiation between these two groups clearly being the ratio of dense bone.

**Table 7.2.2 Relationships between Descriptors**

| | Mesial | Distal | Buccal | Lingual |
|---|---|---|---|---|
| **Distal** | insignificant | | | |
| **Buccal** | p<0.01 | p<0.01 | | |
| **Lingual** | p<0.01 | p<0.01 | insignificant | |
| **Apical** | insignificant | insignificant | p<0.01 | p<0.01 |

Significance of descriptor value scores with regard to other descriptors for all recorded samples in the entire cohort. Variation is insignificant where p>0.05.

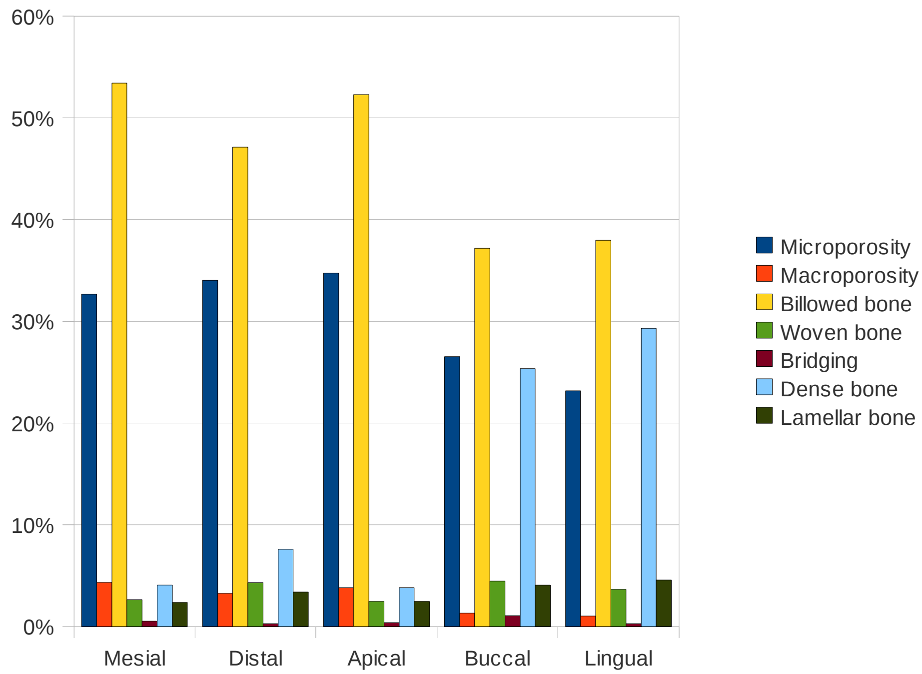


**Figure 7.2.7 Descriptor Distributions by Section**

Frequency distributions of descriptor values for each socket section recorded in the entire cohort.

Although the overall descriptor distributions are made clear in Figure 7.2.7 it is important to note that the dataset is biased in the direction of sockets which are at least 2/3 full. The socket appearance of the various sections at differing stages of fullness may be more or less significantly related. A second round of tests was performed with datasets limited by stage of fullness. The results, in Table 7.2.3, are clear: variation between descriptors becomes more significant as fullness increases. Some relationships – such as those between mesial and distal, mesial and apical, and buccal and lingual descriptors – remain insignificant throughout but others – most notably those between distal and buccal and buccal and apical descriptors – only vary significantly from the third stage and become more significant in stage four. This variation is displayed visually in Figures 7.2.8 to 7.2.11; the similarities between section distributions are clear in the first three stages of fullness but in the final stage discrepancies are apparent, particularly the portion of buccal and lingual sections now occupied by dense bone and the increased proportion of microporosity in the whole socket. Because of the varying significance depending on stage of fullness any consolidation of descriptors based on these tests would be unwise.

**Table 7.2.3 Relationships between Descriptors by Fullness**

| **FULLNESS 1** | **Mesial** | **Distal** | **Buccal** | **Lingual** |
|---|---|---|---|---|
| **Distal** | insignificant | | | |
| **Buccal** | insignificant | insignificant | | |
| **Lingual** | insignificant | insignificant | Insignificant | |
| **Apical** | insignificant | insignificant | insignificant | insignificant |
| **FULLNESS 2** | **Mesial** | **Distal** | **Buccal** | **Lingual** |
| **Distal** | insignificant | | | |
| **Buccal** | insignificant | insignificant | | |
| **Lingual** | insignificant | insignificant | insignificant | |
| **Apical** | insignificant | insignificant | insignificant | insignificant |
| **FULLNESS 3** | **Mesial** | **Distal** | **Buccal** | **Lingual** |
| **Distal** | insignificant | | | |
| **Buccal** | insignificant | $p<0.05$ | | |
| **Lingual** | insignificant | insignificant | insignificant | |
| **Apical** | insignificant | insignificant | $p<0.05$ | insignificant |
| **FULLNESS 4** | **Mesial** | **Distal** | **Buccal** | **Lingual** |
| **Distal** | insignificant | | | |
| **Buccal** | $p<0.01$ | $p<0.01$ | | |
| **Lingual** | $p<0.01$ | $p<0.01$ | insignificant | |
| **Apical** | insignificant | $p>0.05$ | $p<0.01$ | $p<0.01$ |

Significance of descriptor value scores with regard to other descriptors for all recorded samples in samples limited by socket stage of fullness. Variation is insignificant where $p>0.05$.

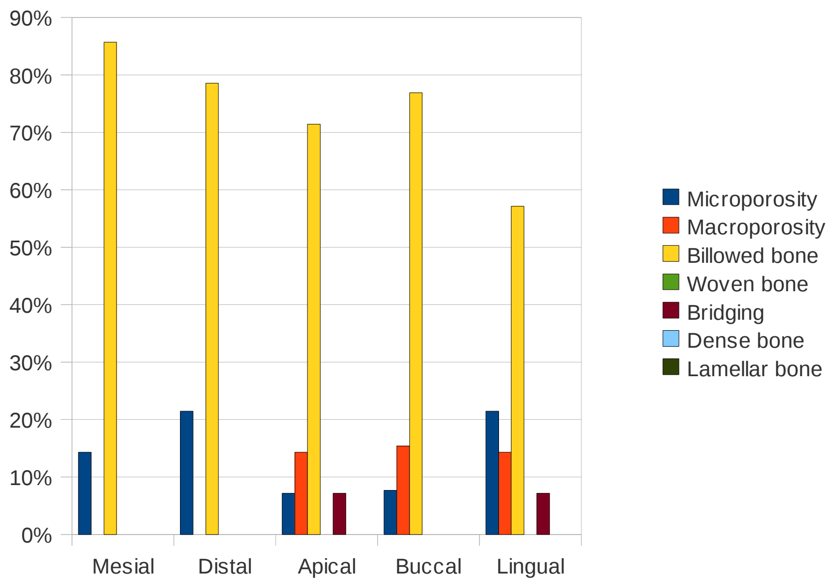


**Figure 7.2.8 Fullness Stage 1 Descriptor Distributions by Section**
Frequency distributions of descriptor values for each socket section recorded in sockets with a fullness stage of 1.

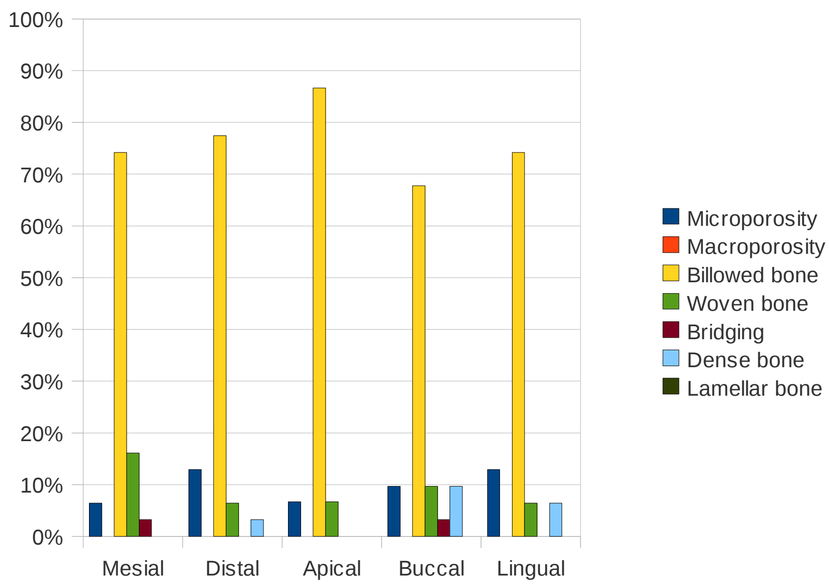


**Figure 7.2.9 Fullness Stage 2 Descriptor Distributions by Section**
Frequency distributions of descriptor values for each socket section recorded in sockets with a fullness stage of 2.

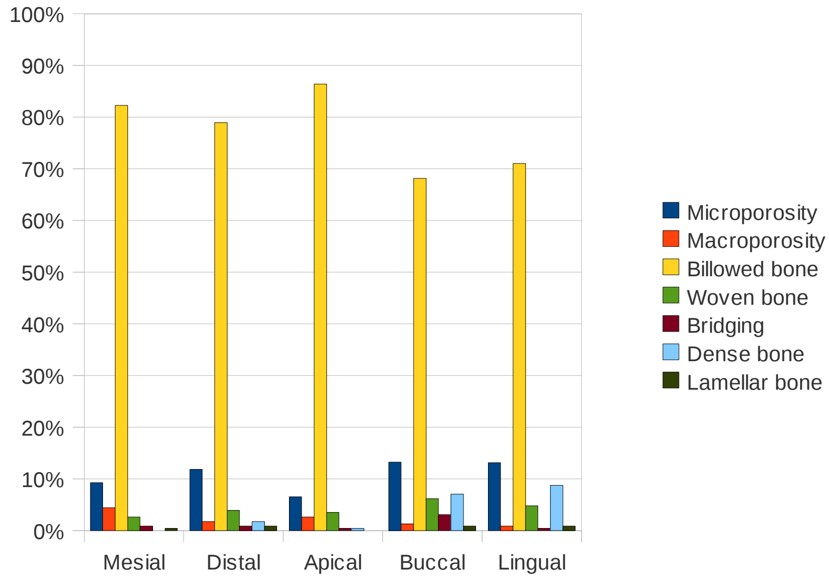


**Figure 7.2.10 Fullness Stage 3 Descriptor Distributions by Section**
Frequency distributions of descriptor values for each socket section recorded in sockets with a fullness stage of 3.

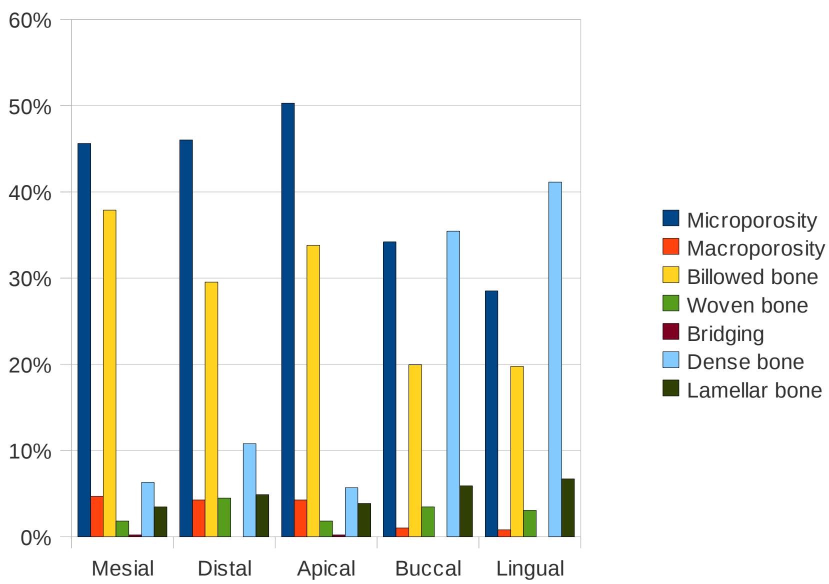


**Figure 7.2.11 Fullness Stage 4 Descriptor Distributions by Section**
Frequency distributions of descriptor values for each socket section recorded in sockets with a fullness stage of 4.

*Influence of variables on TSL*

Clusters were assigned and TSL estimated based on the results from phase 1. Intra-cluster variation in both applicable clusters was assessed for the eight new variables (those which could not be tested in the clinical study). This was assessed for two variable groups (ridge status and all descriptors) and for each individual variable with ANOVAs. The results are in Tables 7.2.4 and 7.2.5, respectively. Average TSL values were calculated for each of the 44 values and those of the variables determined to be significant by ANOVA are in Table 7.2.6. Note the absence of a value for distal ridge presence in the second cluster: this is because it was represented by fewer than four sockets despite being significant. Constants where there are at least four samples however have not been excluded. No further adjustment is necessary for general application of these results. As with the remodeling-centric schedules in phase 1 the TSLs for the second cluster are average estimates for sockets which are remodeling and those for the third cluster are minimums for healed sockets. Comprehensive tables of all results including sample sizes, significance, and standard deviations for all values for all variables and both clusters are in the Appendix.

**Table 7.2.4 Significance Results of Linear Models of Selected Variable Groups**

| Variables | Cluster 2 | Cluster 3 |
|---|---|---|
| Mesial and distal ridges | insignificant | $p<0.01$ |
| Mesial, distal, buccal, lingual, and apical descriptors | insignificant | $p<0.05$ |

Significance of intra-cluster variation of TSL for multiple variables assessed by general linear models. Variation is insignificant where $p>0.05$.

**Table 7.2.5 Significance Results of ANOVAs on Variables**

| Variables | | Cluster 2 | Cluster 3 |
|---|---|---|---|
| DHI | | insignificant | insignificant |
| Ridge status | mesial | insignificant | $p<0.01$ |
| | distal | $p=0.05$* | $p<0.01$ |
| Descriptor | mesial | insignificant | insignificant |
| | distal | insignificant | insignificant |
| | buccal | insignificant | $p<0.05$ |
| | lingual | insignificant | $p<0.01$ |
| | apical | insignificant | $p<0.05$ |

Significance of variation of TSL for the values of a given variable assessed by ANOVA. Variation is insignificant where $p>0.05$. *Distal ridge presence is insufficiently represented (n=3).

**Table 7.2.6 TSL Averages for Values of Significant Variables by Cluster**

| Variable | Value | Cluster 2 | | Cluster 3 | |
|---|---|---|---|---|---|
| | | n | TSL | n | TSL |
| Mesial ridge | present | | | 120 | 31 |
| | absent | | | 273 | 28 |
| Distal ridge* | present | | | 56 | 28 |
| | absent | 16 | 14 | 212 | 27 |
| | distalmost | 10 | 14 | 131 | 27 |
| Buccal descriptor | microporosity | | | 198 | 29 |
| | macroporosity | | | 8 | 28 |
| | billowed bone | | | 252 | 28 |
| | woven bone | | | 31 | 28 |
| | bridging | | | 7 | 31 |
| | dense bone | | | 31 | 30 |
| | smooth lamellar bone | | | 190 | 29 |
| Lingual descriptor* | microporosity | | | 170 | 29 |
| | macroporosity | | | 6 | 26 |
| | billowed bone | | | 259 | 28 |
| | woven bone | | | 26 | 28 |
| | bridging | | | | |
| | dense bone | | | 35 | 30 |
| | smooth lamellar bone | | | 222 | 30 |
| Apical descriptor* | microporosity | | | 262 | 30 |
| | macroporosity | | | 27 | 28 |
| | billowed bone | | | 363 | 28 |
| | woven bone | | | 17 | 27 |
| | bridging | | | | |
| | dense bone | | | 19 | 30 |
| | smooth lamellar bone | | | 29 | 29 |

Average TSL values for each value of those variables which exhibit statistically significant TSL variation. *There are insufficient samples for this variable with the exception of these values.

*Observer error*

Ten individuals with a combined twenty sockets were selected at random from the Bösfeld assemblage. In all variables tested – stage of fullness, all descriptors, indicators of dental health, and ridge status – intra-observer error was found to be insignificant by Student's *t*-

tests. In almost all instances in fact the data were identical. This indicates the above results are as accurate as possible inclusive of observer interference in spite of the qualitative nature of some of the scoring systems and the experiment should have a high likelihood of successful reproduction.

## CHAPTER 8 PHASE 2 CONCLUSIONS

The supported inclusion of new variables which have significant relationships with TSL allows for a more precise – and, without significant observer error, accurate – TSL estimation in for archaeological, forensic, or (albeit limited) clinical application. In conjunction with the remodeling-centric method from phase 1 comprehensive schedules have thus been derived. These may be utilized in either a unabridged or eclectic fashion depending upon the limitations of the method of observation or imaging and data available and recorded. This concludes the primary aim of the study.

In addition to the data directly relating to TSL estimation, a few other points are worth further discussion. In particular the insignificance of dental health index to TSL may be of use to dental practitioners considering treatment plans but with limited resources and concern for both immediate and long-term function. Likely of greater interest to anthropologists however are certain inter-variable relationships as they illuminate a clearly observable specialization of parts of the internal bony socket structure. This specialization is also linked to stage of remodeling (particularly the latter ones), fullness, and TSL as it is absent in the earlier stages of fullness. The results also support the interpretation that interdental ridge resorption, as it is both unrelated to neighboring tooth presence and occurs simultaneously mesially and distally, is only slightly induced by general post-tooth loss residual ridge resorption but instead may be linked to this specialization of portions of the advanced-stage of remodeled socket.

## 8.1 Limitations

To avoid excessive repetition of points previously made, let it simply be stated that bias may be unintentionally factored into the various schedules due to imbalances in sample distributions and would only be apparent through further testing of additional samples or a separate cohort. No apparent bias can be definitively discerned from the tests performed or results derived from these samples. Another possibility lies in subjective bias through observer error, but this is less likely as this factor was found to be insignificant and so have little bearing on either the data collected or results derived from it. Every effort has been made in order to minimize or control all forms of bias and so any persisting invisible significant error is hopefully minor and trivial.

## 8.2 Inter-variable Relationships

Perhaps the most intriguing secondary results consider neighboring tooth presence and ridge resorption. Although not strictly an objective or as intensively investigated as it could be, the relationships between these two variables – or lack thereof – are, although test results indicate that both ridge resorption and neighboring tooth presence are significantly related to TSL, independent ones. Ridge resorption may also be significantly linked to age and pathological interference although such links were not exhaustively investigation in this study.

In addition the relationships between descriptors with regard to stage of fullness are unexpected. The necessity of differentiating between the different sections becomes of greater importance as fullness increases. This leads to several notable conclusions: (1) the remodeling stage of socket healing has a fairly universal internal appearance and bone structure; (2) the more advanced stages of socket ossification are marked by localized differentiation of osseous development and macroscopic appearance; and (3) opposing sections may not necessarily display such differentiation regardless of stage of healing. This final point is upheld by the persistent insignificance of variation between mesial and distal sections or buccal and lingual sections: both of these groups represent opposing sections and yet the macroscopic appearance indicates that the healing process may be more closely related to factors such as vascularization or axial forces than to directional mastication forces or microcosmic mesial drift. This differentiation may also be of keen interest for future research, as the increasing significance of inter-descriptor relationships with increasing fullness – not cluster – means it may be possible to distinguish between stages of ossified sockets and so devise more elaborate estimation schedules for the third cluster.

## 8.3 Practical Application

Due to the TSLs of the samples in this cohort having been estimated from the remodeling-centric schedules derived from the clinical data, no further adjustment (to avoid simply reflecting the data rather than identifying transitional borders between remodeling and remodeled) of the derived schedules will be necessary. Instead these findings are easily applied in conjunction with the remodeling-centric schedules from the clinical study, and ideally all significant variables from both experiments would be assessed per sample. Although the variables in this study were assessed through macroscopic observation of dry bone they may be applied to living or mummified individuals through various other imaging methods such as MRI or CT; ridge status may even be observed through more common radiographic imaging techniques.

# CHAPTER 9 DISCUSSION

Both the primary and secondary aims of this project were met satisfactorily. The comprehensive literature review allowed for a multidisciplinary approach to practical studies of AMTL and subsequent socket healing; the project produced favorable, reliable results which are simply applied. Dissemination of these findings beyond that which has already occurred is intended through topical contributions which will rely on data from both the literary and experimental stages of the study.

Age-specific loss mapping to assess tooth loss patterns throughout an individual's lifetime both on case-by-case and population-wide bases in archaeological samples may lead to new interpretations of causes of tooth loss, more accurate true prevalences of dental disease, and the resulting inferences of diet and oral behaviors. Although the schedule devised here is not as precise as various histological ones, it is suitable given the materials and conditions, and its non-destructive nature makes it particularly well-suited for application in osseous remains. The use of the dental health index devised in section 6.4 may also be utilized to assist in the identification of more cases of ablation in archaeological populations, as an individual with a low index but lacking multiple teeth is unlikely to have lost them due to dental disease. The index might also serve as a comparative tool to assess general dental health within a population either by applying it as directed above or to each individual tooth and socket.

With these favorable results forensics cases may be more likely to take into consideration remodeling stages in order to assist in an odontological profile of an unidentified or suspected individual or as part of bite mark analysis. Clinical dentists with limited access to modern facilities and radiographic imaging may also use this together with other schedules to map past, current, and expected hard tissue activity and status. Implantologists in particular may utilize such schedules to estimate the progression of socket ossification and avoid unnecessary premature radiography following tooth extraction.

Although the findings are appropriate for practical application in a variety of circumstances, further investigation could be greatly beneficial to a fuller interpretation of these results. In particular the relationships between variables with significant variation for one or all stages of remodeling – those which are included in the schedules as significantly influential factors on TSL – are a worthwhile subject. Do the presence or absence of specific conditions (values) of these variables themselves actually accelerate or decelerate the osseous healing process or are they the direct or indirect result of another factor which also influences the rate of bony socket healing? Essentially a better understanding of whether variable significance is correlative or causative would contribute to not only the present findings and similar future studies but also a broader understanding of general oral hard tissue dynamics and the factors which affect them. Perhaps of particular interest would be the investigation into such variables concurrently with analyses of various mastication forces and side preferences in order to comprehend how compressive and tensile forces affect not only socket healing but also general alveolar remodeling. Such investigation may also lend considerable insight into the phenomena of residual ridge resorption and continuous eruption.

This study is unique but some aspects – largely the schedules – mimic portions of previous studies. Although agreement with the present body of literature is not evidence of reliable results, it is reassuring and interesting to note that, despite substantial differences in materials and method, these tests have not produced vastly dissimilar results from many of those utilizing techniques such as histology. A thorough testing of those standards and methodologies employed in the experiments reported here on both similar and different populations and ideally with a cohort which is more evenly distributed (in terms of socket location, etc.) would help to assess inter-population variation. The addition of more advanced imaging technology such as CT scans could also be to considerable advantage to both assess more closely those variables which were invisible in the clinical cohort and to ascertain if more specific post-ossified stages can be differentiated between. Even without such comparative investigations however the research presented here exceeds original expectations, meets all desired objectives, and is reliable and suitable for immediate application.

## APPENDIX

Contained in this appendix are all TSL data for all variables and values for both the limited and remodeling-centric schedules including sample sizes, significance, and standard deviations in addition to trimmed and untrimmed values for both clinical and archaeological cohorts. Although those variables which present both statistically significant variation for a given cluster and are also represented by a sufficient sample size have been utilized in the results and conclusions chapters, these full schedules may be further utilized either for reference for future work in the area of osseous socket remodeling or to provide additional information on all the variables tested with the stipulation that most of these are not intended for gross practical application but only to provide a general idea of the complete findings. Finally blank forms and reference tables for easy application of the limited-TSL and remodeling-centric/archaeological schedules have been formulated and reproduced below.

### A.1 Limited-TSL Schedules

**Table A.1.1 Full Limited-TSL Results for Cluster 1**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Total cluster | 1 (pre-osseous) | 70 | 3 | 2 | 7 |
| Sex | Male | 48 | 2 | 2 | 3 |
| | Female | 22 | 3 | 1 | 12 |
| Age | <20 years | 19 | 5 | 2 | 13 |
| | 20-50 years | 45 | 2 | 2 | 3 |
| | >50 years | 6 | 1 | 1 | 1 |
| Number of teeth lost (continued on next page) | 1 | | | | |
| | 2 | 4 | 0 | | |
| | 3 | 6 | 4 | 4 | 5 |
| | 4 | 33 | 3 | 1 | 10 |

**Table A.1.1 continued on next page**

Table A.1.1 (continued from previous page)

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Number of teeth lost (continued from previous page) | 5 | 4 | 3 | 3 | 7 |
| | 6 | 2 | 6 | | |
| | 7 | | | | |
| | 8 | 9 | 0 | | |
| | 9 | 1 | 0 | | |
| | 10 | | | | |
| | 11 | 9 | 3 | 3 | 2 |
| | 12 | | | | |
| | 14 | | | | |
| | 15 | | | | |
| | 16 | | | | |
| | 17 | | | | |
| | 19 | | | | |
| | 21 | | | | |
| | 31 | 1 | 0 | | |
| | 32 | 1 | 0 | | |
| Socket site (continued on next page) | 11 | | | | |
| | 12 | 1 | 6 | | |
| | 13 | | | | |
| | 14 | | | | |
| | 15 | | | | |
| | 16 | | | | |
| | 17 | | | | |
| | 18 | 9 | 7 | 4 | 19 |
| | 21 | | | | |
| | 22 | 1 | 6 | | |
| | 23 | | | | |
| | 24 | | | | |
| | 25 | 1 | 0 | | |
| | 26 | 1 | 5 | | |
| | 27 | 1 | 5 | | |
| | 28 | 7 | 1 | 1 | 2 |
| | 31 | | | | |
| | 32 | | | | |

Table A.1.1 continued on next page

**Table A.1.1 (continued from previous page)**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Socket site (continued from previous page) | 33 | | | | |
| | 34 | | | | |
| | 35 | | | | |
| | 36 | 3 | 2 | | 3 |
| | 37 | 3 | 2 | | 3 |
| | 38 | 16 | 2 | 2 | 4 |
| | 41 | | | | |
| | 42 | | | | |
| | 43 | | | | |
| | 44 | 1 | 0 | | |
| | 45 | 2 | 1 | | 1 |
| | 46 | 3 | 3 | | 6 |
| | 47 | 3 | 1 | | 1 |
| | 48 | 18 | 2 | 1 | 3 |
| Arch | 1 | 10 | 7 | 4 | 17 |
| | 2 | 11 | 2 | 2 | 2 |
| | 3 | 22 | 2 | 2 | 4 |
| | 4 | 27 | 2 | 1 | 3 |
| Tooth number | 1 | | | | |
| | 2 | 2 | 6 | | |
| | 3 | | | | |
| | 4 | 1 | 0 | | |
| | 5 | 3 | 1 | | 1 |
| | 6 | 7 | 3 | 3 | 4 |
| | 7 | 7 | 2 | 2 | 2 |
| | 8 | 50 | 3 | 1 | 8 |
| Jaw | Maxillary | 21 | 4 | 2 | 12 |
| | Mandibular | 49 | 2 | 1 | 3 |
| Side | Right | 37 | 3 | 1 | 9 |
| | Left | 33 | 2 | 2 | 3 |
| Site category 1 | Incisors | 2 | 6 | | |
| | Canines | | | | |
| | Premolars | 4 | 1 | 0 | 1 |
| | Molars | 64 | 3 | 1 | 7 |

**Table A.1.1 continued on next page**

**Table A.1.1 (continued from previous page)**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Site category 2 | Anterior | 2 | 6 | | |
| | Posterior | 68 | 2 | 1 | 7 |
| Mesial tooth | Present | 62 | 3 | 1 | 8 |
| | Absent | 8 | 2 | 2 | 2 |
| Distal tooth | Present | 8 | 2 | 1 | 3 |
| | Absent | 12 | 3 | 3 | 3 |
| | Distalmost | 50 | 3 | 1 | 8 |
| Occlusal tooth | Present | 20 | 2 | 2 | 4 |
| | Absent | 50 | 3 | 1 | 8 |
| Cause of tooth loss | None | 4 | 0 | | |
| | Caries | 4 | 0 | | |
| | Periodontal disease | 15 | 3 | 3 | 3 |
| | Orthodontia | 1 | 0 | | |
| | Impaction/maleruption | 5 | 0 | | |
| | Trauma | 2 | 5 | | 7 |
| | Third molar crowding/maleruption | 39 | 3 | 2 | 9 |
| Interference | None | 57 | 2 | 1 | 8 |
| | Alveolar defect | 13 | 3 | 3 | 3 |
| | Periodontitis | | | | |
| | Sinusitis | | | | |
| | Jaw fracture | | | | |
| Treatment at the time of tooth extraction (continued on next page) | None | 21 | 2 | 2 | 3 |
| | Any | 49 | 3 | 1 | 8 |
| | Without antibiotics | 39 | 3 | 2 | 9 |
| | With antibiotics | 31 | 2 | 1 | 3 |
| | Without NSAIDs | 61 | 3 | 2 | 8 |
| | With NSAIDs | 9 | 1 | 1 | 1 |
| | Without analgesics | 67 | 3 | 2 | 7 |
| | With analgesics | 3 | 2 | | 2 |
| | No use of non-chlorhexidine-containing rinse | 48 | 2 | 2 | 4 |
| | Use of non-chlorhexidine-containing rinse | 22 | 3 | 1 | 12 |
| | No use of chlorhexidine-containing rinse | 48 | 3 | 1 | 8 |
| | Use of chlorhexidine-containing rinse | 22 | 3 | 2 | 4 |

**Table A.1.1 continued on next page**

**Table A.1.1 (continued from previous page)**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Treatment at the time of tooth extraction (continued from previous page) | Without collagen | 65 | 3 | 2 | 7 |
| | With collagen | 5 | 1 | 1 | 1 |
| | With other (unclassified) medication | 62 | 3 | 2 | 8 |
| | Without other (unclassified) medication | 8 | 1 | 1 | 1 |
| Fullness | Stage 1 | 70 | 3 | 2 | 7 |
| Radiolucency | Stage 1 | 24 | 5 | 3 | 11 |
| | Stage 2 | 34 | 2 | 1 | 3 |
| | Stage 3 | 10 | 1 | 1 | 0 |
| | Stage 4 | | | | |
| | Stage 5 | | | | |
| Complications | None | 64 | 2 | 1 | 7 |
| | Local inflammation | 2 | 11 | | |
| | Local defect/infection | 3 | 0 | | |
| | Alveolar osteitis | 1 | 0 | | |
| | Other | | | | |
| Treatment at follow-up | None | 25 | 5 | 2 | 11 |
| | Any | 45 | 1 | 1 | 3 |
| | Without antibiotics | 52 | 3 | 2 | 8 |
| | With antibiotics | 18 | 2 | 1 | 4 |
| | Without NSAIDs | 69 | 3 | 2 | 7 |
| | With NSAIDs | 1 | 0 | | |
| | Without analgesics | 69 | 3 | 2 | 7 |
| | With analgesics | 1 | 0 | | |
| | No use of non-chlorhexidine-containing rinse | 65 | 2 | 1 | 7 |
| | Use of non-chlorhexidine-containing rinse | 5 | 4 | 4 | 6 |
| | No use of chlorhexidine-containing rinse | 29 | 5 | 3 | 11 |
| | Use of chlorhexidine-containing rinse | 41 | 1 | 1 | 2 |
| | Without collagen | 65 | 2 | 1 | 7 |
| | With collagen | 5 | 4 | 4 | 6 |
| | With other (unclassified) medication | 68 | 3 | 2 | 7 |
| | Without other (unclassified) medication | 2 | 0 | | |

Variable values with insufficient sample sizes or constants lack a trimmed average and the latter also lacks a standard deviation; these have been highlighted in yellow. Variable values with a sample size of 0 are in gray. Values of variables which exhibit significant variation are in blue.

**Table A.1.2 Full Limited-TSL Results for Cluster 2**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Total cluster | 2 (remodeling) | 55 | 15 | 14 | 15 |
| Sex | Male | 29 | 11 | 10 | 12 |
| | Female | 26 | 20 | 18 | 17 |
| Age | <20 years | 12 | 15 | 14 | 15 |
| | 20-50 years | 36 | 17 | 15 | 16 |
| | >50 years | 7 | 10 | 10 | 5 |
| Number of teeth lost | 1 | | | | |
| | 2 | 5 | 19 | 20 | 7 |
| | 3 | | | | |
| | 4 | 28 | 12 | 11 | 10 |
| | 5 | | | | |
| | 6 | | | | |
| | 7 | | | | |
| | 8 | 10 | 28 | 27 | 27 |
| | 9 | 3 | 14 | | 5 |
| | 10 | 2 | 6 | | 4 |
| | 11 | 1 | 16 | | |
| | 12 | | | | |
| | 14 | 1 | 17 | | |
| | 15 | | | | |
| | 16 | | | | |
| | 17 | 1 | 7 | | |
| | 19 | 2 | 6 | | |
| | 21 | 2 | 18 | | 6 |
| | 31 | | | | |
| | 32 | | | | |
| Socket site (continued on next page) | 11 | 2 | 15 | | 6 |
| | 12 | | | | |
| | 13 | | | | |
| | 14 | | | | |
| | 15 | | | | |
| | 16 | | | | |
| | 17 | | | | |
| | 18 | 7 | 5 | 5 | 5 |

**Table A.1.2 continued on next page**

**Table A.1.2 (continued from previous page)**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Socket site (continued from previous page) | 21 | | | | |
| | 22 | | | | |
| | 23 | | | | |
| | 24 | 1 | 7 | | |
| | 25 | | | | |
| | 26 | 1 | 14 | | |
| | 27 | 1 | 17 | | |
| | 28 | 9 | 14 | 13 | 14 |
| | 31 | 1 | 6 | | |
| | 32 | | | | |
| | 33 | | | | |
| | 34 | | | | |
| | 35 | 2 | 18 | | 6 |
| | 36 | 1 | 9 | | |
| | 37 | 4 | 47 | 46 | 25 |
| | 38 | 13 | 20 | 20 | 13 |
| | 41 | 1 | 6 | | |
| | 42 | | | | |
| | 43 | | | | |
| | 44 | | | | |
| | 45 | | | | |
| | 46 | 5 | 14 | 14 | 10 |
| | 47 | 1 | 16 | | |
| | 48 | 6 | 5 | 4 | 5 |
| Arch | 1 | 9 | 7 | 7 | 7 |
| | 2 | 12 | 14 | 13 | 12 |
| | 3 | 21 | 24 | 22 | 19 |
| | 4 | 13 | 9 | 9 | 8 |
| Tooth number (continued on next page) | 1 | 4 | 10 | 10 | 6 |
| | 2 | | | | |
| | 3 | | | | |
| | 4 | 1 | 7 | | |
| | 5 | 2 | 18 | | 6 |
| | 6 | 7 | 13 | 13 | 9 |

**Table A.1.2 continued on next page**

**Table A.1.2 (continued from previous page)**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Tooth number (continued from previous page) | 7 | 6 | 37 | 35 | 25 |
| | 8 | 35 | 13 | 12 | 13 |
| Jaw | Maxillary | 21 | 11 | 10 | 10 |
| | Mandibular | 34 | 18 | 16 | 17 |
| Side | Right | 22 | 8 | 8 | 8 |
| | Left | 33 | 20 | 18 | 17 |
| Site category 1 | Incisors | 4 | 10 | 10 | 6 |
| | Canines | | | | |
| | Premolars | 3 | 14 | | 8 |
| | Molars | 48 | 16 | 14 | 16 |
| Site category 2 | Anterior | 4 | 10 | 10 | 6 |
| | Posterior | 51 | 16 | 14 | 16 |
| Mesial tooth | Present | 44 | 14 | 13 | 11 |
| | Absent | 11 | 22 | 20 | 24 |
| Distal tooth | Present | 10 | 13 | 13 | 8 |
| | Absent | 10 | 27 | 25 | 23 |
| | Distalmost | 35 | 13 | 12 | 13 |
| Occlusal tooth | Present | 17 | 24 | 21 | 18 |
| | Absent | 38 | 12 | 10 | 12 |
| Cause of tooth loss | None | 8 | 29 | 27 | 26 |
| | Caries | 3 | 6 | | 1 |
| | Periodontal disease | 9 | 15 | 15 | 7 |
| | Orthodontia | 1 | 17 | | |
| | Impaction/maleruption | | | | |
| | Trauma | 1 | 0 | | |
| | Third molar crowding/maleruption | 32 | 13 | 12 | 13 |
| Interference | None | 37 | 15 | 13 | 17 |
| | Alveolar defect | 14 | 18 | 18 | 19 |
| | Periodontitis | 2 | 6 | | 4 |
| | Sinusitis | 1 | 14 | | |
| | Jaw fracture | 1 | 0 | | |

**Table A.1.2 continued on next page**

**Table A.1.2 (continued from previous page)**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Treatment at the time of tooth extraction | None | 25 | 17 | 15 | 19 |
| | Any | 30 | 14 | 13 | 11 |
| | Without antibiotics | 40 | 16 | 15 | 17 |
| | With antibiotics | 15 | 12 | 12 | 7 |
| | Without NSAIDs | 53 | 16 | 14 | 15 |
| | With NSAIDs | 2 | 5 | | 5 |
| | Without analgesics | 53 | 14 | 13 | 14 |
| | With analgesics | 2 | 44 | | |
| | No use of non-chlorhexidine-containing rinse | 41 | 17 | 15 | 17 |
| | Use of non-chlorhexidine-containing rinse | 14 | 12 | 11 | 8 |
| | No use of chlorhexidine-containing rinse | 39 | 14 | 12 | 16 |
| | Use of chlorhexidine-containing rinse | 16 | 18 | 17 | 12 |
| | Without collagen | 54 | 15 | 14 | 15 |
| | With collagen | 1 | 7 | | |
| | With other (unclassified) medication | 49 | 16 | 14 | 16 |
| | Without other (unclassified) medication | 6 | 12 | 11 | 9 |
| Fullness | Stage 2 | 19 | 8 | 8 | 7 |
| | Stage 3 | 14 | 15 | 14 | 14 |
| | Stage 4 | 21 | 22 | 20 | 19 |
| Radiolucency | Stage 1 | 2 | 14 | | |
| | Stage 2 | 11 | 13 | 13 | 13 |
| | Stage 3 | 29 | 11 | 11 | 11 |
| | Stage 4 | 9 | 31 | 29 | 25 |
| | Stage 5 | 2 | 15 | | 6 |
| Complications | None | 51 | 16 | 14 | 16 |
| | Local inflammation | 4 | 9 | 9 | 4 |
| | Local defect/infection | | | | |
| | Alveolar osteitis | | | | |
| | Other | | | | |
| Treatment at follow-up (continued on next page) | None | 22 | 19 | 17 | 19 |
| | Any | 33 | 13 | 12 | 11 |
| | Without antibiotics | 35 | 18 | 17 | 17 |
| | With antibiotics | 20 | 10 | 9 | 10 |

**Table A.1.2 continued on next page**

**Table A.1.2 (continued from previous page)**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Treatment at follow-up (continued from previous page) | Without NSAIDs | 55 | 15 | 14 | 15 |
| | With NSAIDs | | | | |
| | Without analgesics | 53 | 16 | 14 | 15 |
| | With analgesics | 2 | 5 | | 2 |
| | No use of non-chlorhexidine-containing rinse | 40 | 15 | 14 | 16 |
| | Use of non-chlorhexidine-containing rinse | 15 | 15 | 14 | 2 |
| | No use of chlorhexidine-containing rinse | 33 | 17 | 15 | 16 |
| | Use of chlorhexidine-containing rinse | 22 | 13 | 11 | 13 |
| | Without collagen | 52 | 15 | 14 | 15 |
| | With collagen | 3 | 16 | | 9 |
| | With other (unclassified) medication | 52 | 15 | 13 | 15 |
| | Without other (unclassified) medication | 3 | 23 | | 15 |

Variable values with insufficient sample sizes or constants lack a trimmed average and the latter also lacks a standard deviation; these have been highlighted in yellow. Variable values with a sample size of 0 are in gray. Values of variables which exhibit significant variation are in blue.

**Table A.1.3 Full Limited-TSL Results for Cluster 3**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Total cluster | 3 (ossified) | 71 | 80 | 78 | 65 |
| Sex | Male | 39 | 108 | 108 | 73 |
| | Female | 32 | 46 | 46 | 26 |
| Age | <20 years | 17 | 54 | 52 | 32 |
| | 20-50 years | 36 | 117 | 117 | 70 |
| | >50 years | 18 | 33 | 31 | 22 |
| Number of teeth lost (continued on next page) | 1 | 2 | 166 | | 79 |
| | 2 | 6 | 99 | 99 | 32 |
| | 3 | 1 | 87 | | |
| | 4 | 19 | 61 | 56 | 48 |
| | 5 | 2 | 14 | | 20 |
| | 6 | 2 | 200 | | |
| | 7 | 1 | 83 | | |
| | 8 | 7 | 45 | 45 | 19 |
| | 9 | 10 | 51 | 51 | 27 |

**Table A.1.3 continued on next page**

**Table A.1.3 (continued from previous page)**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Number of teeth lost (continued from previous page) | 10 | | | | |
| | 11 | 6 | 169 | 175 | 75 |
| | 12 | 4 | 58 | 57 | 19 |
| | 14 | | | | |
| | 15 | 4 | 194 | | |
| | 16 | 1 | 27 | | |
| | 17 | | | | |
| | 19 | 6 | 23 | 23 | 18 |
| | 21 | | | | |
| | 31 | | | | |
| | 32 | | | | |
| Socket site (continued on next page) | 11 | 4 | 69 | 68 | 19 |
| | 12 | 1 | 200 | | |
| | 13 | 1 | 44 | | |
| | 14 | | | | |
| | 15 | | | | |
| | 16 | 2 | 98 | | 51 |
| | 17 | 5 | 83 | 79 | 64 |
| | 18 | 3 | 39 | | 11 |
| | 21 | | | | |
| | 22 | 1 | 200 | | |
| | 23 | | | | |
| | 24 | | | | |
| | 25 | 2 | 17 | | 4 |
| | 26 | 5 | 97 | 95 | 70 |
| | 27 | 1 | 199 | | |
| | 28 | 6 | 118 | 117 | 78 |
| | 31 | 3 | 23 | | 20 |
| | 32 | | | | |
| | 33 | | | | |
| | 34 | | | | |
| | 35 | | | | |
| | 36 | 3 | 91 | | 94 |
| | 37 | 2 | 142 | | 81 |

**Table A.1.3 continued on next page**

Table A.1.3 (continued from previous page)

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Socket site (continued from previous page) | 38 | 8 | 49 | 49 | 36 |
| | 41 | 3 | 23 | | 20 |
| | 42 | | | | |
| | 43 | | | | |
| | 44 | 1 | 27 | | |
| | 45 | 3 | 82 | | 98 |
| | 46 | 5 | 92 | 89 | 60 |
| | 47 | 4 | 155 | 156 | 68 |
| | 48 | 8 | 49 | 49 | 23 |
| Arch | 1 | 16 | 78 | 74 | 53 |
| | 2 | 15 | 108 | 107 | 78 |
| | 3 | 16 | 64 | 60 | 61 |
| | 4 | 24 | 76 | 73 | 46 |
| Tooth number | 1 | 10 | 41 | 41 | 29 |
| | 2 | 2 | 200 | | |
| | 3 | 1 | 44 | | |
| | 4 | 1 | 27 | | |
| | 5 | 5 | 56 | 51 | 78 |
| | 6 | 15 | 94 | 92 | 62 |
| | 7 | 12 | 126 | 127 | 71 |
| | 8 | 25 | 64 | 59 | 53 |
| Jaw | Maxillary | 31 | 93 | 90 | 67 |
| | Mandibular | 40 | 71 | 68 | 62 |
| Side | Right | 40 | 76 | 73 | 59 |
| | Left | 31 | 85 | 83 | 72 |
| Site category 1 | Incisors | 12 | 68 | 64 | 67 |
| | Canines | 1 | 44 | | |
| | Premolars | 6 | 51 | 45 | 70 |
| | Molars | 52 | 87 | 85 | 64 |
| Site category 2 | Anterior | 13 | 66 | 62 | 65 |
| | Posterior | 58 | 84 | 81 | 65 |
| Mesial tooth | Present | 48 | 80 | 77 | 61 |
| | Absent | 23 | 80 | 78 | 74 |

Table A.1.3 continued on next page

**Table A.1.3 (continued from previous page)**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Distal tooth | Present | 26 | 73 | 69 | 59 |
| | Absent | 20 | 110 | 111 | 77 |
| | Distalmost | 25 | 64 | 59 | 53 |
| Occlusal tooth | Present | 34 | 84 | 82 | 59 |
| | Absent | 37 | 77 | 73 | 70 |
| Cause of tooth loss (continued on next page) | None | 13 | 103 | 100 | 59 |
| | Caries | 14 | 54 | 52 | 42 |
| | Periodontal disease | 25 | 110 | 111 | 81 |
| | Orthodontia | | | | |
| | Impaction/maleruption | 3 | 55 | | 18 |
| Cause of tooth loss (cont. from previous page) | Trauma | | | | |
| | Third molar crowding/maleruption | 16 | 44 | 43 | 25 |
| Interference | None | 39 | 71 | 67 | 48 |
| | Alveolar defect | 28 | 101 | 101 | 81 |
| | Periodontitis | | | | |
| | Sinusitis | 4 | 31 | 30 | 26 |
| | Jaw fracture | | | | |
| Treatment at the time of tooth extraction | None | 36 | 104 | 104 | 79 |
| | Any | 35 | 56 | 54 | 32 |
| | Without antibiotics | 60 | 84 | 81 | 69 |
| | With antibiotics | 11 | 62 | 63 | 32 |
| | Without NSAIDs | 67 | 79 | 76 | 66 |
| | With NSAIDs | 4 | 98 | 98 | 42 |
| | Without analgesics | 66 | 82 | 80 | 67 |
| | With analgesics | 5 | 55 | 53 | 25 |
| | No use of non-chlorhexidine-containing rinse | 58 | 88 | 86 | 68 |
| | Use of non-chlorhexidine-containing rinse | 13 | 45 | 43 | 24 |
| | No use of chlorhexidine-containing rinse | 50 | 88 | 86 | 73 |
| | Use of chlorhexidine-containing rinse | 21 | 63 | 62 | 35 |
| | Without collagen | 70 | 80 | 78 | 65 |
| | With collagen | 1 | 76 | | |
| | With other (unclassified) medication | 67 | 81 | 78 | 66 |
| | Without other (unclassified) medication | 4 | 70 | 70 | 25 |

**Table A.1.3 continued on next page**

**Table A.1.3 (continued from previous page)**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Fullness | Stage 5 | 33 | 86 | 84 | 67 |
| | Stage 6 | 38 | 75 | 72 | 63 |
| Radiolucency | Stage 1 | | | | |
| | Stage 2 | 2 | 36 | | 28 |
| | Stage 3 | 3 | 61 | | 33 |
| | Stage 4 | 33 | 60 | 56 | 51 |
| | Stage 5 | 28 | 117 | 117 | 72 |
| Complications | None | 69 | 79 | 77 | 64 |
| | Local inflammation | 1 | 27 | | |
| | Local defect/infection | 1 | 200 | | |
| | Alveolar osteitis | | | | |
| | Other | | | | |
| Treatment at follow-up | None | 67 | 82 | 79 | 66 |
| | Any | 4 | 53 | 53 | 24 |
| | Without antibiotics | 70 | 81 | 78 | 65 |
| | With antibiotics | 1 | 27 | | |
| | Without NSAIDs | 71 | 80 | 78 | 65 |
| | With NSAIDs | | | | |
| | Without analgesics | 71 | 80 | 78 | 65 |
| | With analgesics | | | | |
| | No use of non-chlorhexidine-containing rinse | 70 | 80 | 78 | 65 |
| | Use of non-chlorhexidine-containing rinse | 1 | 77 | | |
| | No use of chlorhexidine-containing rinse | 68 | 81 | 78 | 66 |
| | Use of chlorhexidine-containing rinse | 3 | 62 | | 20 |
| | Without collagen | 71 | 80 | 78 | 65 |
| | With collagen | | | | |
| | With other (unclassified) medication | 71 | 80 | 78 | 65 |
| | Without other (unclassified) medication | | | | |

Variable values with insufficient sample sizes or constants lack a trimmed average and the latter also lacks a standard deviation; these have been highlighted in yellow. Variable values with a sample size of 0 are in gray. Values of variables which exhibit significant variation are in blue.

## A.2 Remodeling-centric Schedules

Note the absence of a schedule here for the second cluster, as it is identical to that for the TSL-limited schedule (Table A.1.2). For the first cluster the averages have been calculated by subtracting the standard deviation for a given value of a given variable from the respective untrimmed or trimmed (if available) average (in Table A.2.1). For the third cluster the averages have been calculated by adding the standard deviation for a given value of a given variable to the respective untrimmed or trimmed (if available) average (in Table A.2.2).

**Table A.2.1 Full Remodeling-centric Results for Cluster 1**

| Variable | Value | Average | 5% trimmed average |
|---|---|---|---|
| Total cluster | 1 (pre-osseous) | 0 | -1 |
| Sex | Male | -1 | -2 |
| | Female | 3 | 1 |
| Age | <20 years | -1 | -2 |
| | 20-50 years | 0 | -2 |
| | >50 years | 5 | 5 |
| Number of teeth lost (continued on next page) | 1 | | |
| | 2 | 12 | 13 |
| | 3 | | |
| | 4 | 1 | 1 |
| | 5 | | |
| | 6 | | |
| | 7 | | |
| | 8 | 1 | 0 |
| | 9 | 10 | |
| | 10 | 2 | |
| | 11 | | |
| | 12 | | |
| | 14 | | |
| | 15 | | |

**Table A.2.1 continued on next page**

**Table A.2.1 (continued from previous page)**

| Variable | Value | Average | 5% trimmed average |
|---|---|---|---|
| Number of teeth lost (continued from previous page) | 16 | | |
| | 17 | | |
| | 19 | | |
| | 21 | 11 | |
| | 31 | | |
| | 32 | | |
| Socket site (continued on next page) | 11 | 8 | |
| | 12 | | |
| | 13 | | |
| | 14 | | |
| | 15 | | |
| | 16 | | |
| | 17 | | |
| | 18 | 0 | -1 |
| | 21 | | |
| | 22 | | |
| | 23 | | |
| | 24 | | |
| | 25 | | |
| | 26 | | |
| | 27 | | |
| | 28 | 0 | -1 |
| | 31 | | |
| | 32 | | |
| | 33 | | |
| | 34 | | |
| | 35 | 11 | |
| | 36 | | |
| | 37 | 21 | 21 |
| | 38 | 7 | 7 |
| | 41 | | |
| | 42 | | |
| | 43 | | |
| | 44 | | |

**Table A.2.1 continued on next page**

**Table A.2.1 (continued from previous page)**

| Variable | Value | Average | 5% trimmed average |
|---|---|---|---|
| Socket site (continued from previous page) | 45 | | |
| | 46 | 4 | 3 |
| | 47 | | |
| | 48 | 0 | -1 |
| Arch | 1 | 0 | 0 |
| | 2 | 2 | 1 |
| | 3 | 5 | 3 |
| | 4 | 1 | 0 |
| Tooth number | 1 | 4 | 4 |
| | 2 | | |
| | 3 | | |
| | 4 | | |
| | 5 | 11 | |
| | 6 | 5 | 4 |
| | 7 | 12 | 10 |
| | 8 | 0 | -1 |
| Jaw | Maxillary | 0 | -1 |
| | Mandibular | 1 | -1 |
| Side | Right | 1 | 0 |
| | Left | 3 | 1 |
| Site category 1 | Incisors | 4 | 4 |
| | Canines | | |
| | Premolars | 6 | |
| | Molars | 0 | -2 |
| Site category 2 | Anterior | 4 | 4 |
| | Posterior | 0 | -1 |
| Mesial tooth | Present | 2 | 1 |
| | Absent | -2 | -4 |
| Distal tooth | Present | 5 | 5 |
| | Absent | 4 | 2 |
| | Distalmost | 0 | -1 |
| Occlusal tooth | Present | 5 | 3 |
| | Absent | 0 | -2 |

**Table A.2.1 continued on next page**

**Table A.2.1 (continued from previous page)**

| Variable | Value | Average | 5% trimmed average |
| --- | --- | --- | --- |
| Cause of tooth loss | None | -1 | -2 |
| | Caries | 6 | |
| | Periodontal disease | 8 | 8 |
| | Orthodontia | | |
| | Impaction/maleruption | | |
| | Trauma | | |
| | Third molar crowding/maleruption | | |
| Interference | None | -2 | -4 |
| | Alveolar defect | 9 | 9 |
| | Periodontitis | 2 | |
| | Sinusitis | | |
| | Jaw fracture | | |
| Treatment at the time of tooth extraction | None | -2 | 2 |
| | Any | 3 | 2 |
| | Without antibiotics | -1 | -2 |
| | With antibiotics | 5 | 5 |
| | Without NSAIDs | 0 | -1 |
| | With NSAIDs | 0 | |
| | Without analgesics | 0 | -2 |
| | With analgesics | | |
| | No use of non-chlorhexidine-containing rinse | 0 | -2 |
| | Use of non-chlorhexidine-containing rinse | 1 | 4 |
| | No use of chlorhexidine-containing rinse | -2 | -4 |
| | Use of chlorhexidine-containing rinse | 6 | 6 |
| | Without collagen | 0 | -1 |
| | With collagen | | |
| | With other (unclassified) medication | 0 | -2 |
| | Without other (unclassified) medication | 2 | 2 |
| Complications | None | 0 | -1 |
| | Local inflammation | 5 | 5 |
| | Local defect/infection | | |
| | Alveolar osteitis | | |
| | Other | | |

**Table A.2.1 continued on next page**

**Table A.2.1 (continued from previous page)**

| Variable | Value | Average | 5% trimmed average |
|---|---|---|---|
| Treatment at follow-up | None | 0 | -3 |
| | Any | 2 | 0 |
| | Without antibiotics | 2 | 0 |
| | With antibiotics | 0 | -1 |
| | Without NSAIDs | 0 | -1 |
| | With NSAIDs | | |
| | Without analgesics | 0 | -1 |
| | With analgesics | 2 | |
| | No use of non-chlorhexidine-containing rinse | -1 | -3 |
| | Use of non-chlorhexidine-containing rinse | 3 | 2 |
| | No use of chlorhexidine-containing rinse | 1 | -1 |
| | Use of chlorhexidine-containing rinse | -1 | -2 |
| | Without collagen | 0 | -2 |
| | With collagen | 7 | |
| | With other (unclassified) medication | 0 | -2 |
| | Without other (unclassified) medication | 8 | |

All these TSLs are maximum estimates for sockets with no osseous remodeling activity; for practical purposes any negative values would be converted to a score of 0 (weeks). Variable values with insufficient sample sizes or constants for the second cluster dataset lack a trimmed average and the latter also lacks a standard deviation; these have been highlighted in yellow. Variable values with a sample size of 0 for the second cluster are in gray. Values of variables which exhibit significant variation for the second cluster are in blue. Stages of radiolucency have not been included as this variable increases as stage of fullness does.

**Table A.2.2 Full Remodeling-centric Results for Cluster 3**

| Variable | Value | Average | 5% trimmed average |
|---|---|---|---|
| Total cluster | 3 (ossified) | 30 | 29 |
| Sex | Male | 23 | 21 |
| | Female | 37 | 35 |
| Age | <20 years | 30 | 29 |
| | 20-50 years | 33 | 31 |
| | >50 years | 15 | 15 |
| Number of teeth lost (continued on next page) | 1 | | |
| | 2 | 26 | 26 |
| | 3 | | |
| | 4 | 22 | 21 |
| | 5 | | |

**Table A.2.2 continued on next page**

**Table A.2.2 (continued from previous page)**

| Variable | Value | Average | 5% trimmed average |
|---|---|---|---|
| Number of teeth lost (continued from previous page) | 6 | | |
| | 7 | | |
| | 8 | 55 | 54 |
| | 9 | 19 | |
| | 10 | 10 | |
| | 11 | | |
| | 12 | | |
| | 14 | | |
| | 15 | | |
| | 16 | | |
| | 17 | | |
| | 19 | | |
| | 21 | 24 | |
| | 31 | | |
| | 32 | | |
| Socket site (continued on next page) | 11 | 21 | |
| | 12 | | |
| | 13 | | |
| | 14 | | |
| | 15 | | |
| | 16 | | |
| | 17 | | |
| | 18 | 10 | 10 |
| | 21 | | |
| | 22 | | |
| | 23 | | |
| | 24 | | |
| | 25 | | |
| | 26 | | |
| | 27 | | |
| | 28 | 28 | 27 |
| | 31 | | |
| | 32 | | |
| | 33 | | |
| | 34 | | |

**Table A.2.2 continued on next page**

**Table A.2.2 (continued from previous page)**

| Variable | Value | Average | 5% trimmed average |
|---|---|---|---|
| Socket site (continued from previous page) | 35 | 24 | |
| | 36 | | |
| | 37 | 72 | 72 |
| | 38 | 33 | 33 |
| | 41 | | |
| | 42 | | |
| | 43 | | |
| | 44 | | |
| | 45 | | |
| | 46 | 24 | 24 |
| | 47 | | |
| | 48 | 9 | 9 |
| Arch | 1 | 14 | 13 |
| | 2 | 26 | 25 |
| | 3 | 42 | 40 |
| | 4 | 18 | 17 |
| Tooth number | 1 | 17 | 16 |
| | 2 | | |
| | 3 | | |
| | 4 | | |
| | 5 | 24 | |
| | 6 | 22 | 22 |
| | 7 | 62 | 61 |
| | 8 | 25 | 24 |
| Jaw | Maxillary | 21 | 20 |
| | Mandibular | 35 | 33 |
| Side | Right | 16 | 15 |
| | Left | 37 | 35 |
| Site category 1 | Incisors | 16 | 16 |
| | Canines | | |
| | Premolars | 22 | |
| | Molars | 32 | 30 |
| Site category 2 | Anterior | 16 | 16 |
| | Posterior | 31 | 30 |

**Table A.2.2 continued on next page**

Table A.2.2 (continued from previous page)

| Variable | Value | Average | 5% trimmed average |
|---|---|---|---|
| Mesial tooth | Present | 25 | 24 |
| | Absent | 47 | 45 |
| Distal tooth | Present | 20 | 20 |
| | Absent | 50 | 48 |
| | Distalmost | 25 | 24 |
| Occlusal tooth | Present | 42 | 40 |
| | Absent | 24 | 22 |
| Cause of tooth loss | None | 33 | 31 |
| | Caries | 7 | |
| | Periodontal disease | 23 | 23 |
| | Orthodontia | | |
| | Impaction/maleruption | | |
| | Trauma | | |
| | Third molar crowding/maleruption | | |
| Interference | None | 32 | 30 |
| | Alveolar defect | 28 | 27 |
| | Periodontitis | 10 | |
| | Sinusitis | | |
| | Jaw fracture | | |
| Treatment at the time of tooth extraction | None | 36 | 34 |
| | Any | 25 | 24 |
| | Without antibiotics | 34 | 32 |
| | With antibiotics | 19 | 19 |
| | Without NSAIDs | 31 | 29 |
| | With NSAIDs | 9 | |
| | Without analgesics | 29 | 27 |
| | With analgesics | | |
| | No use of non-chlorhexidine-containing rinse | 33 | 32 |
| | Use of non-chlorhexidine-containing rinse | 19 | 19 |
| | No use of chlorhexidine-containing rinse | 30 | 28 |
| | Use of chlorhexidine-containing rinse | 30 | 29 |
| | Without collagen | 31 | 29 |
| | With collagen | | |
| | With other (unclassified) medication | 31 | 30 |
| | Without other (unclassified) medication | 21 | 20 |

Table A.2.2 (continued on next page)

**Table A.2.2 (continued from previous page)**

| Variable | Value | Average | 5% trimmed average |
|---|---|---|---|
| Complications | None | 31 | 30 |
| | Local inflammation | 12 | 12 |
| | Local defect/infection | | |
| | Alveolar osteitis | | |
| | Other | | |
| Treatment at follow-up | None | 38 | 36 |
| | Any | 24 | 23 |
| | Without antibiotics | 35 | 34 |
| | With antibiotics | 19 | 18 |
| | Without NSAIDs | 30 | 29 |
| | With NSAIDs | | |
| | Without analgesics | 31 | 29 |
| | With analgesics | 7 | |
| | No use of non-chlorhexidine-containing rinse | 32 | 30 |
| | Use of non-chlorhexidine-containing rinse | 27 | 25 |
| | No use of chlorhexidine-containing rinse | 33 | 31 |
| | Use of chlorhexidine-containing rinse | 26 | 25 |
| | Without collagen | 31 | 29 |
| | With collagen | 26 | |
| | With other (unclassified) medication | 30 | 28 |
| | Without other (unclassified) medication | 38 | |

All these TSLs are minimum estimates for fully-modeled sockets. Variable values with insufficient sample sizes or constants for the second cluster dataset lack a trimmed average and the latter also lacks a standard deviation; these have been highlighted in yellow. Variable values with a sample size of 0 for the second cluster are in gray. Values of variables which exhibit significant variation for the second cluster are in blue. Stages of radiolucency have not been included as this variable increases as stage of fullness does.

## A.3 Archaeological Schedules[14]

**Table A.3.1 Full Archaeological Results for Cluster 2**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| DHI | 2 | 1 | 12 | | |
| | 3 | 19 | 15 | 15 | 2 |
| | 4 | 24 | 15 | 15 | 2 |
| Mesial ridge | Present | 13 | 15 | 15 | 2 |
| | Absent | 19 | 15 | 15 | 2 |
| Distal ridge | Present | 3 | 14 | | 2 |
| | Absent | 16 | 14 | 14 | 2 |
| | Socket distalmost | 10 | 14 | 14 | 2 |
| Mesial descriptor | Microporosity | 4 | 15 | 15 | 2 |
| | Macroporosity | | | | |
| | Billowed bone | 35 | 15 | 15 | 2 |
| | Woven bone | 5 | 13 | 13 | 1 |
| | Bridging | 1 | 16 | | |
| | Dense bone | | | | |
| | Smooth lamellar bone | | | | |
| Distal descriptor | Microporosity | 7 | 14 | 14 | 2 |
| | Macroporosity | | | | |
| | Billowed bone | 35 | 15 | 15 | 2 |
| | Woven bone | 2 | 13 | | 1 |
| | Bridging | | | | |
| | Dense bone | | | | |
| | Smooth lamellar bone | 1 | 17 | | |
| Buccal descriptor | Microporosity | 4 | 17 | 17 | 2 |
| | Macroporosity | 2 | 14 | | |
| | Billowed bone | 31 | 15 | 15 | 2 |
| | Woven bone | 3 | 14 | | 2 |
| | Bridging | 1 | 13 | | |
| | Dense bone | | | | |
| | Smooth lamellar bone | 3 | 14 | | 3 |
| Lingual descriptor (continued on next page) | Microporosity | 7 | 16 | 15 | 2 |
| | Macroporosity | 2 | 15 | | 1 |
| | Billowed bone | 31 | 15 | 15 | 2 |

**Table A.3.1 continued on next page**

14 Note that the absence of schedules for the first cluster are because sockets without evidence of osseous remodeling are, in osteoarchaeological remains, not identified as evidence for AMTL.

**Table A.3.1 (continued from previous page)**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Lingual descriptor (continued from previous page) | Woven bone | 2 | 13 | | 1 |
| | Bridging | 1 | 11 | | |
| | Dense bone | | | | |
| | Smooth lamellar bone | 2 | 15 | | 3 |
| Apical descriptor | Microporosity | 3 | 16 | | 2 |
| | Macroporosity | 2 | 15 | | 1 |
| | Billowed bone | 26 | 15 | 15 | 2 |
| | Woven bone | 2 | 14 | | 1 |
| | Bridging | 1 | 12 | | |
| | Dense bone | | | | |
| | Smooth lamellar bone | | | | |

Variable values with insufficient sample sizes or constants lack a trimmed average and the latter also lacks a standard deviation; these have been highlighted in yellow. Variable values with a sample size of 0 are in gray. Values of variables which exhibit significant variation are in blue.

**Table A.3.2 Full Archaeological Results for Cluster 3**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| DHI | 2 | 24 | 29 | 29 | 4 |
| | 3 | 378 | 29 | 29 | 4 |
| | 4 | 281 | 29 | 29 | 5 |
| Mesial ridge | Present | 120 | 31 | 31 | 5 |
| | Absent | 273 | 28 | 28 | 4 |
| Distal ridge | Present | 56 | 28 | 28 | 4 |
| | Absent | 212 | 27 | 27 | 4 |
| | Socket distalmost | 131 | 27 | 27 | 4 |
| Mesial descriptor | Microporosity | 245 | 29 | 29 | 5 |
| | Macroporosity | 33 | 30 | 30 | 5 |
| | Billowed bone | 372 | 29 | 29 | 4 |
| | Woven bone | 15 | 27 | 27 | 5 |
| | Bridging | 3 | 27 | | 3 |
| | Dense bone | 18 | 28 | 28 | 4 |
| | Smooth lamellar bone | 31 | 28 | 27 | 4 |
| Distal descriptor (continued on next page) | Microporosity | 253 | 29 | 29 | 5 |
| | Macroporosity | 25 | 31 | 31 | 5 |
| | Billowed bone | 325 | 29 | 28 | 4 |

**Table A.3.2 continued on next page**

**Table A.3.2 (continued from previous page)**

| Variable | Value | n samples | Average | 5% trimmed average | Standard deviation |
|---|---|---|---|---|---|
| Distal descriptor (continued from previous page) | Woven bone | 31 | 29 | 29 | 4 |
| | Bridging | 2 | 28 | | 2 |
| | Dense bone | 26 | 28 | 28 | 5 |
| | Smooth lamellar bone | 57 | 29 | 29 | 4 |
| Buccal descriptor | Microporosity | 198 | 29 | 29 | 5 |
| | Macroporosity | 8 | 28 | 28 | 4 |
| | Billowed bone | 252 | 28 | 28 | 4 |
| | Woven bone | 31 | 28 | 28 | 4 |
| | Bridging | 7 | 31 | 31 | 4 |
| | Dense bone | 31 | 30 | 30 | 5 |
| | Smooth lamellar bone | 190 | 29 | 29 | 5 |
| Lingual descriptor | Microporosity | 170 | 29 | 29 | 4 |
| | Macroporosity | 6 | 26 | 26 | 3 |
| | Billowed bone | 259 | 28 | 28 | 4 |
| | Woven bone | 26 | 28 | 28 | 4 |
| | Bridging | 1 | 21 | | |
| | Dense bone | 35 | 30 | 30 | 5 |
| | Smooth lamellar bone | 222 | 30 | 30 | 5 |
| Apical descriptor | Microporosity | 262 | 30 | 30 | 5 |
| | Macroporosity | 27 | 28 | 28 | 5 |
| | Billowed bone | 363 | 28 | 28 | 4 |
| | Woven bone | 17 | 27 | 27 | 3 |
| | Bridging | 2 | 32 | | 4 |
| | Dense bone | 19 | 30 | 30 | 4 |
| | Smooth lamellar bone | 29 | 28 | 29 | 4 |

Variable values with insufficient sample sizes or constants lack a trimmed average and the latter also lacks a standard deviation; these have been highlighted in yellow. Variable values with a sample size of 0 are in gray. Values of variables which exhibit significant variation are in blue.

## A.4 Blank Forms and Reference Tables

These tables are intended for application as detailed in the relevant results and conclusions chapters. For most purposes the clinical remodeling-centric and archaeological form (Table A.4.3) is that which will be most frequently employed in an eclectic manner through the exclusion of factors which are not recorded (such as the use of antibiotics in archaeological assemblages); at the minimum cluster must be assigned to the socket with additional significant variables only serving to increase precision.

**Table A.4.1 Limited-TSL Estimation Form**

| Variable | Value | TSL | Value | TSL | Value | TSL |
|---|---|---|---|---|---|---|
| Cluster | 1 | 2 | 2 | 14 | 3 | 78 |
| Sex | | | | | | |
| Age | | | | | | |
| Arch | | | | | | |
| Side | | | | | | |
| Distal tooth | | | | | | |
| Occlusal tooth | | | | | | |
| Interference | | | | | | |
| Any treatment at the time of extraction? | | | | | | |
| Application of non-chlorhexidine containing antiseptic rinse at the time of extraction? | | | | | | |
| Stage of fullness | | | | | | |
| Stage of radiolucency | | | | | | |
| Treatment with antibiotics at follow-up? | | | | | | |
| Application of chlorhexidine-containing rinse at follow-up? | | | | | | |
| **TSL Estimate (average)** | | | | | | |

Boxes in gray indicate that the variable is not included in TSL prediction due to statistically insignificant variation in the original sample. The TSL estimates already entered for the cluster values are based on trimmed averages.

**Table A.4.2 Limited-TSL Reference Table**

| Variable | Value | TSL | Value | TSL | Value | TSL |
|---|---|---|---|---|---|---|
| Cluster | 1 | 2 | 2 | 14 | 3 | 78 |
| Sex | | | male | 10 | male | 108 |
| | | | female | 18 | female | 46 |
| Age | | | | | >20 | 52 |
| | | | | | 20-50 | 117 |
| | | | | | >50 | 31 |
| Arch | | | 1 | 7 | | |
| | | | 2 | 13 | | |
| | | | 3 | 22 | | |
| | | | 4 | 9 | | |
| Side | | | right | 8 | | |
| | | | left | 18 | | |
| Distal tooth | | | present | 13 | present | 69 |
| | | | absent | 25 | absent | 111 |
| | | | distalmost | 12 | distalmost | 59 |
| Occlusal tooth | | | present | 21 | | |
| | | | absent | 10 | | |
| Interference | | | | | none | 67 |
| | | | | | alveolar defect | 101 |
| Any treatment at the time of extraction? | | | | | no | 104 |
| | | | | | yes | 54 |
| Application of non-chlorhexidine containing antiseptic rinse at the time of extraction? | | | | | no | 86 |
| | | | | | yes | 43 |
| Stage of fullness | | | 2 | 8 | | |
| | | | 3 | 14 | | |
| | | | 4 | 20 | | |
| Stage of radiolucency | | | | | 4 | 56 |
| | | | | | 5 | 117 |
| Treatment with antibiotics at follow-up? | | | no | 17 | | |
| | | | yes | 9 | | |
| Application of chlorhexidine-containing rinse at follow-up? | no | 3 | | | | |
| | yes | 1 | | | | |

Boxes in gray indicate that the variable is not included in TSL prediction due to statistically insignificant variation in the original sample. Those values which were represented by insufficient sample sizes or constants have been omitted. The estimates are based on trimmed averages.

**Table A.4.3 Remodeling-centric TSL Estimation Form**

| Variable | Value | TSL | Value | TSL | Value | TSL |
|---|---|---|---|---|---|---|
| Cluster | 1 | 0 | 2 | 14 | 3 | 29 |
| Sex | | | | | | |
| Arch | | | | | | |
| Side | | | | | | |
| Distal tooth | | | | | | |
| Occlusal tooth | | | | | | |
| Mesial ridge | | | | | | |
| Distal ridge | | | | | | |
| Buccal descriptor | | | | | | |
| Lingual descriptor | | | | | | |
| Apical descriptor | | | | | | |
| Stage of fullness | | | | | | |
| Treatment with antibiotics at follow-up? | | | | | | |
| **TSL Estimate (average)** | | | | | | |

Boxes in gray indicate that the variable is not included in TSL prediction due to statistically insignificant variation in the original sample. The TSL estimates already entered for the cluster values are based on trimmed averages.

**Table A.4.4 Remodeling-centric TSL Reference Table**

| Variable | Value | TSL | Value | TSL | Value | TSL |
|---|---|---|---|---|---|---|
| Cluster | 1 | 0 | 2 | 14 | 3 | 29 |
| Sex | male | 0 | male | 10 | male | 21 |
| | female | 1 | female | 18 | female | 35 |
| Arch | 1 | 0 | 1 | 7 | 1 | 13 |
| | 2 | 1 | 2 | 13 | 2 | 25 |
| | 3 | 3 | 3 | 22 | 3 | 40 |
| | 4 | 0 | 4 | 9 | 4 | 17 |
| Side | right | 0 | right | 8 | right | 15 |
| | left | 1 | left | 18 | left | 35 |
| Distal tooth | present | 5 | present | 13 | present | 20 |
| | absent | 2 | absent | 25 | absent | 48 |
| | distalmost | 0 | distalmost | 12 | distalmost | 24 |
| Occlusal tooth | present | 3 | present | 21 | present | 40 |
| | absent | 0 | absent | 10 | absent | 22 |
| Mesial ridge | | | | | present | 31 |
| | | | | | absent | 28 |

**Table A.4.4 continued on next page**

**Table A.4.4 (continued from previous page)**

| Variable | Value | TSL | Value | TSL | Value | TSL |
|---|---|---|---|---|---|---|
| Distal ridge | | | absent or distalmost | 14 | present | 28 |
| | | | | | absent or distalmost | 27 |
| Buccal descriptor | | | | | microporosity or lamellar bone | 29 |
| | | | | | macroporosity or billowed or woven bone | 28 |
| | | | | | bridging | 31 |
| | | | | | dense bone | 30 |
| Lingual descriptor | | | | | microporosity | 29 |
| | | | | | macroporosity | 26 |
| | | | | | billowed or woven bone | 28 |
| | | | | | dense or lamellar bone | 30 |
| Distal ridge | | | | | microporosity or dense bone | 30 |
| | | | | | macroporosity or billowed bone | 28 |
| | | | | | woven bone | 27 |
| | | | | | lamellar bone | 29 |
| Stage of fullness | | | 2 | 8 | | |
| | | | 3 | 14 | | |
| | | | 4 | 20 | | |
| Treatment with antibiotics at follow-up? | no | 0 | no | 17 | no | 34 |
| | yes | 0 | yes | 9 | yes | 18 |

Boxes in gray indicate that the variable is not included in TSL prediction due to statistically insignificant variation in the original sample. Those values which were represented by insufficient sample sizes or constants have been omitted. The estimates are based on trimmed averages. Negative estimates have been adjusted to 0.

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**ACKNOWLEDGEMENTS**

There are too many people to thank individually for their help in all aspects of the monumental undertaking that is embarking upon doctoral research.  I would like to sincerely thank all those who listened and assisted professionally and personally throughout the process.  A few stellar individuals stand out in particular however and so I must acknowledge:

[redacted] – for all his encouragement and support and for providing access to and information on the Barbican assemblage in Sheffield;

[redacted] – for enthusiastically providing his perspective, expertise, and access to his patient files; and also his staff for their generous and patient efforts on his behalf;

[redacted] – for kindly sending me otherwise inaccessible articles and related unpublished material;

[redacted] – for his skill in taking terrible sketches and instructions and making exactly the picture I have in mind;

[redacted] – for keeping me as sane as one can be and offering feedback on the crazy ideas and methods I ran their way during the process, particularly non-human primate (monkey) applications, and additional thanks to the former two for invaluable translation assistance;

[redacted] – for generally being magical when it came to administration, visas, contracts, and fixing everything that ever went wrong, which was everything;

[redacted] – for technical assistance and extreme patience in the field;

and all those who gave their thoughts and critiques on and attention to the various overzealous early presentations of aspects of this material at the 2009 Kongress der Gesellschaft für Anthropologie, 2010 European Meeting of the Paleopathological Association, and 2010 Congress of the European Anthropological Association.

To everybody who provided caffeine, laughter, and listening to get me through the many all-nighters and perpetual disasters: I can't believe what I put you all through, and I'm so happy you accept cake as bribery/payment. I definitely couldn't have done it without you guys. I look forward to hearing you all call me Dr. Morgan.

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The work presented here has not yet been published although it is currently being prepared for various peer-reviewed journals. Parts of this dissertation have however already been presented at international conferences:

Morgan J and Alt KW. 2009. Identification of Five Causes of Antemortem Tooth Loss (AMTL) from Dry Bone. Internationaler Kongress der Gesellschaft für Anthropologie/International Congress of the Anthropological Society; Munich. [poster]

Morgan J and Alt KW. 2009. Observable Stages and Scheduling for Alveolar Remodeling following Antemortem Tooth Loss (AMTL). Internationaler Kongress der Gesellschaft für Anthropologie/International Congress of the Anthropological Society; Munich. [podium]

Morgan J and Alt KW. 2010. A (Re)Classification of Periodontal Disease. European Meeting of the Paleopathology Association; Vienna. [podium]

Morgan J and Alt KW. 2010. The Anthropology of Tooth Extraction. Congress of the European Anthropological Association; Poznan. [podium]