Factors Governing the Quantity and Shape of Alveolar Bone in the Edentulous Maxilla and Mandible

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Abstract

Bone is constantly undergoing remodeling of its bony matrix in response to various stimuli impinged upon the tissue. Bony remodeling occurs in both the dentate and edentulous states, but the edentulous lose more bone over time. This study analyzed sex, age and years edentulous for their influence on the height, width and shape of the anterior residual alveolar ridge of the jaws. Significantly greater amounts of mandibular residual alveolar bone height were found in males ($p<0.0001$) and in those with more edentulous years in the maxilla ($p=0.003$). The maxilla showed significantly greater amounts of residual alveolar bone height in the group with fewer edentulous years ($p=0.004$). No significant associations were detected when sex, age and years edentulous were compared with anterior maxillary bone width. Statistical analysis of this study population also revealed no significant associations between sex, age, and years edentulous and anterior maxillary bone shape.

Abstract

La matrice et le réseau de vaisseaux sanguins des os sont en constant remodelage qui est une réponse à la variété de stimuli que reçoivent les tissus. Le remodelage de l'os survient chez les personnes avec dentition complète comme chez les personnes édentées, tandis qu'une résorption graduelle et continue se produit chez les personnes édentées seulement. Dans cette étude, le sexe, l'âge et le nombre d'années d'édentation ont été analysés afin de cerner leur influence sur la hauteur, la largeur et la forme de la crête alvéolaire antérieure résiduelle de la mâchoire. On a trouvé que l'os alvéolaire mandibulaire résiduel était significativement plus grand chez les hommes ($p<0.0001$) et chez ceux qui ont le plus grand nombre d'années d'édentation maxillaire ($p<0.003$). Au maxillaire, la hauteur de l'os alvéolaire résiduel était significativement plus grande dans les groupes présentant un nombre d'années d'édentation moins élevé ($p=0.004$). Aucune association significative n'a été détectée quant au sexe, à l'âge et aux années d'édentation lorsqu'on les a comparés à la largeur de l'os maxillaire antérieur. Également, l'analyse statistique effectuée sur la population à l'étude n'a révélé aucune association entre le sexe, l'âge ou les années d'édentation et la forme de l'os maxillaire antérieur.

Introduction

Alveolar bone loss in the oral cavity can be attributed to many sources. Systemic diseases such as HIV infection, diabetes mellitus or genetic diseases like Down's Syndrome, may increase the susceptibility of loss of bone in the mouth. Local factors are usually responsible for a diminishing oral bone mass. The predominant cause of bone loss in the oral cavity can be attributed to periodontal disease and tooth loss.

Periodontal disease usually involves the infection of periodontal tissues by various pathogens that may or may not involve the destruction of bony tissue. Periodontitis is defined by loss of bone and soft tissue attachment. This loss of bone can occur at any age and at varying rates. Studies done on periodontitis have linked various bacterial pathogens to the destruction of bone supporting the teeth (Jeffcoat, 1993). The host response to these invaders has also been implicated in bone loss. Prostaglandins, which are inflammatory mediators, have been universally accepted to be involved with bone destruction and loss. Enzymes like collagenase and others produced by bacteria have been shown to induce destruction of the components of the bony matrix (Jeffcoat, 1993). Advanced periodontal disease or trauma may require the extraction of teeth. Tooth loss is a major contributor to the loss of bone in the jaws. Edentulous people tend to lose bone, especially alveolar bone, over time.

Purpose of the project:

This study has three hypotheses:

1. Does sex, age or years edentulous influence the height of the anterior residual alveolar ridge?

This hypothesis was studied using panoramic radiographs. A panoramic radiograph is a radiograph that shows the full extent of the mandible, maxilla and all facial structures on a single film. It is a non-invasive, relatively inexpensive, fairly simple image to acquire. The patient stands or sits still while the x-ray beam and film travel around their head. The focal trough is an imaginary three-dimensional curved zone in the panoramic machine where the image created by the x-ray beam will be clearly defined. The teeth and jaws must be positioned in the focal trough to obtain a diagnostic panoramic radiograph. Any structure located in front or behind this zone may appear blurred, magnified or reduced in size. If the patient is placed more toward the beam, the structures will appear elongated horizontally. If they are farther from the beam, the structures will appear compressed. A rotation of the midsagittal plane results in distortion. Proper posture of the patient during the procedure is also important because a slumped over position results in a radiopaque superimposition in the mandibular midline caused by the cervical spine. When the patient is properly positioned, a panoramic radiograph can depict many important facial structures. This procedure is also desirable due to its relatively low radiation dose it gives tot he patient. The use of intensifying screens largely contributes to reducing the dose to about the equivalent of four bitewing films or less.

The main disadvantage to the use of panoramic radiography is the resolution. Positioning all structures in the focal trough is impossible and therefore magnification and distortion are usually encountered. Alveolar bone height can be magnified10-40%. The magnification varies from anterior to posterior and is different from one machine to the other. As well, due to the method of imaging the jaws in the panoramic radiograph, it cannot be used to evaluate the width of the bone.

In this study, panoramic radiographs were used to measure bone height in the maxillae and mandibles of an edentulous sample population. The measurements of interest did not require fine detail, so the resolution of the radiographs was sufficient. The bone heights were measured in the canine regions of the jaws. Although distortion may be considered a factor in the anterior region, Xie et al (1997, 1996) indicated that measurement in this region could be clinically applicable, even despite vertical head displacement. All landmarks used were clearly visible in every radiograph studied.

Other studies have looked at the changes in height of the maxillary residual ridge (Atwood, 1971; Carlsson & Persson, 1967), but have employed the use of lateral cephalographs. These studies traced the shape of the maxillae and examined the morphological changes in the jaws, but did not take into account age, sex and years edentulous.

2. Does sex, age or years edentulous influence the width of the maxillary anterior residual alveolar ridge?

This was investigated using lateral cephalographs. A lateral cephalograph is a lateral skull projection. The patient's head is positioned vertically, with the Frankfort plane horizontal. A head holder called a cephalostat, which keeps the patient centred in the x-ray beam, securely positions the head. The film is placed on the left side of the head, perpendicular to the x-rays. Because the left side of the head is closer to the x-ray source, the structures on the right side can be more magnified than the left side. Placing the x-ray tube further away from the patient reduces this magnification difference. The position of the film relative to the patient also contributes to the magnification of the resultant image. The closer the film to the patient's head, the smaller the magnification of the image. The magnification of the images on the midline can be measured.

The main disadvantage of lateral cephalographs is the superimposition of left and right bony structures. This film is only used to measure the width and height of alveolar bone on the midline. In this study, we looked at bony landmarks in the midline of the patient, so superimposition of structures was not a major problem. The landmarks of interest were clearly visible in each radiograph. As well, the same machine was used to take every film. Three trained technicians took all radiographs using the same technique.

Although the width of alveolar bone is very important in evaluating the jaws for procedures like implants, bone width has not been particularly studied in the literature. The literature is even more deficient when it comes to research on the width of maxillary alveolar bone. Many classic studies have employed the use of lateral cephalographs (Mercier et al., 1979; Carlsson et al., 1967; Tuncay et al., 1984, Tallgren, 1972), but did not examine changes in width. Studies, which have looked at width, have used dry skulls (Cawood et al., 1988), alginate impressions (Johnson, 1963) or lateral cephalographs (Atwood, 1971), but these studies do not examine the contribution of age or sex to alveolar ridge resorption. Tracings of the ridges over time were superimposed, a general trend was established, and a pattern of bone loss was suggested. The use of lateral cephalographs provides an excellent non-invasive method of analyzing bone. This study intends to analyze the effect of sex, age and years edentulous on the width of bone using multivariate statistics.

3. Does sex, age or years edentulous influence the shape of the anterior residual alveolar ridge?

Computed tomography (CT) was used to determine the shape of the maxillary alveolar bone. A CT scan is a very useful tool in studying anatomical structures. This method of imaging uses x-rays to produce a cross-sectional image of an object, at a particular thickness, without superimposition of the structures within that object. Ionizing radiation is passed through an object and the image is due to the varying levels of attenuation of the beam within the object. CT scanners have electronic detectors, instead of film, which receive the attenuated x-rays and transmit this information to a computer. At this point, images can be reconstructed from the information obtained. These slices can be manipulated by the computer to produce an image in the orientation chosen by the operator.

There are three main advantages to this technique of image acquisition. First, CT scans produce images with good spatial resolution. Second, within each slice, the computer can differentiate between slight differences (<1%) in the attenuation of the beam. Third, the data is digitally acquired, so there is much flexibility in the storage, analysis and manipulation of the images.

There are three main disadvantages to the use of computer tomography. First, the radiation dose to the patient is higher to that received from plain-film radiography. Second, CT scans are very expensive. The equipment costs approach the millions of dollars, and the individual costs to the patient are in the hundreds. Lastly, the patient must remain motionless for a longer period of time. This is especially important if two and three-dimensional reformatting of the slices is desired.

In this study, CT scans were used to determine the shape of the maxilla in the anterior region for comparison to the classifications proposed by Lekholm and Zarb. Reconstructions of the anterior maxilla gave a clear view of the morphology of the residual alveolar ridge without any superimposition of adjacent structures. Lekholm and Zarb do not describe the age, sex, or edentulous years of the patients who presented the various shapes of bone in their classification system. This study will attempt to establish a classification of these bone shapes that will take into account the age, sex and years edentulous of the patients and see if there is some kind of predictable pattern. Clinically, a model of the edentulous maxilla could help predict bone shape and quantity in men and women at various ages and after a period of edentulousness. This could help prosthodontists in the evaluation of their patients for implant planning.

This section includes a review of studies carried out over the past forty years that have looked at changes in the alveolar bone of edentulous ridges.

Literature Review of Alveolar Bone Loss

- **Changes in bone following tooth loss**

Bone is constantly undergoing remodeling of its matrix and reorganization of its network of blood vessels. This bone activity is in response to various stimuli. Remodeling occurs through recruitment of bone forming cells, osteoblasts, and bone eating cells, osteoclasts. Normally, remodeling does not result in any net loss of bone due to a close coupling of the processes of bone formation and resorption. However, this coupling seems to be disbanded over time by an unknown cause, resulting in a diminishing amount of bone mass. In the oral cavity, this is very well demonstrated when teeth are removed. Upon loss of teeth, the residual alveolar ridge of the jaws undergoes extensive remodeling which results in resorption of the bone. The organization of the osteons within the bone of the jaws undergoes change and specific regions become more resorptive or depository. Enlow demonstrated that the alveolar ridge of the mandible is the region where the resorptive process is most extensive (Enlow et al., 1976).

The presence of teeth in the jaws seems to provide some retention properties to the bone. This is clearly demonstrated in alveolar bone loss studies that compare edentulous individuals using conventional dentures (all the teeth missing) to those using overdentures (2 anterior canines remaining under the denture) (Crum et al., 1978, Xie et al., 1997). Crum observed that patients with complete dentures experienced eight times more bone loss than those with overdentures supported by endodontically treated mandibular canines. Xie et al. (1997) have compared bone height between dentate and edentulous individuals. They observed that the bodies of the mandible and maxilla were significantly greater in dentate patients than in edentulous patients in similar age groups.

- **Classification of bone loss**

The pattern of bone loss in the edentulous jaws has been extensively studied for the last 40 years. Although there has been shown to be a high variability between individuals, there exists a clear trend in the way bone is lost in the jaws. In effort to simplify the staging of alveolar bone resorption in patients, researchers have developed classification systems for the degrees of alveolar ridge atrophy over time. Tallgren established her classification system through a mixed longitudinal study spanning 25 years (Tallgren, 1972). Atwood documented six orders of anterior residual ridge forms in 1963 (Atwood, 1971). Most recently, Cawood and Howell (1988) classified the jaws on a sample of dried skulls.

It is very well established in the literature that the residual alveolar ridge undergoes bone remodeling and extensive resorption over time. The determination of a pattern to this bone loss process has been the object of many studies. Atwood (1979) established a classification system of six orders that illustrates the pattern of bone loss in the jaws.

Order I is the pre-extraction state of the alveolar ridge. The tooth is still present within its socket. Order II shows the alveolar ridge at post-extraction, where the remaining sharp edges of the socket are reabsorbed and rounded off to yield the shape of Order III. The ridge can be described as being high and well-rounded. As time elapses, resorption begins on the residual alveolar ridge, more markedly on the lingual and labial sides. This increasing narrowing of the ridge produces a "knife edge" appearance, which is order IV. The knife-edge progressively becomes narrower and shorter as resorption continues over time and the remaining ridge becomes order V, which looks low and well rounded. Ultimately, after much resorption of the ridge, the basal bone begins to resorb and a depression or Order VI evolves. Although this was the trend of resorption in other studies (Cawood et al., 1988), it must be kept in mind that the pattern of resorption varies from individual to individual as well as within the individual at various sites on the ridge. Enlow observed the pattern of loss in alveolar ridge specimens of who have lost teeth. They found that the mandibles resorb in an inferior, posterior direction. In addition, the extensive resorptive pattern cause morphologic changes in the bone, for example, a forward rotation of the mandible, a downward angulation of the ramus, which gives the individual the typical edentulous look of a protruded mandible. The degree of resorption differs within the jaws themselves. It has been demonstrated that the reduction of bone is less marked on the lingual side of the jaws as compared to the labial side in the incisor/canine region (Enlow et al., 1976).

- **Pattern of Bone Loss in Alveolar Ridge Resorption**

Theoretically, properly fitting dentures would be a cheap, non-invasive solution to the complete loss of teeth. This would be possible, provided the bony ridges on which the dentures are designed to fit remain constant. The reality is that, following tooth extraction, the alveolar ridge continues over time to undergo bony remodeling and resorption. Anatomically, this remodeling results in an alteration in facial morphology. Facial height changes, and the pattern of bone loss in the jaws cause changes in the profile of the edentulous patient. The jaws do not remodel uniformly due to the differing duration that the different teeth remain in the jaws. The premolar/molar teeth in the mandible, for example, are usually lost sooner than the anterior teeth between the mental foramina. This situation results in a shorter alveolar ridge in the premolar region (Pietrokovski et al., 1973).

The anterior portion of the maxilla and mandible undergo loss in height and width. Cephalometric studies have traced bone shape in the jaws to demonstrate the resorption pattern in width (Cawood et al, 1988, Nishimura et al, 1992, Atwood and Coy, 1971). These studies have observed that ridge becomes progressively shorter and thinner over time. The decrease in width over time gives the appearance of a "knife-edge" in a lateral view of the anterior jaws. Johnson (1963) observed the changes in the horizontal and vertical dimension of the maxilla for 1 year from the time of extraction. Patients did not wear dentures for the first ten to twenty weeks of healing and were then given prostheses. Measurements, along several reference planes, were taken on a series of models obtained with alginate impressions, which were taken every two months. The loss in width was equal to the sum of the changes occurring on the labial or buccal aspect and those occurring on the lingual aspect at the same level. These results revealed that the loss in height in the anterior segments ranged from 2.5 to 5.0mm and 3.0 to 7.0mm in the posterior. The loss in width for both regions was between 3.0 and 7.0mm. Generally, it was shown that loss in width exceeded that in height.

Continued alveolar resorption has been shown in people who consistently wear dentures. Tallgren (1972) compared the change in alveolar ridge height between two groups of people who have used dentures for specific amounts of time. A new set of complete dentures was given to each subject at the start of the study. The first group was comprised of patients who had been wearing dentures for seven years and were followed for eight years, giving them a total of fifteen years experience. The other group wore dentures for ten years and was followed for twenty-five years. This study, as in the Johnson study, showed that the rate of alveolar bone resorption was greatest in the first year of wearing dentures. The following years showed a consistent decrease of approximately ten percent of the rate of the first year. The total amount of bone loss in the fifteen-year experience group was 7.7mm in the mandible and 2.2mm in the maxilla. The twenty-five year group had an average decrease of 9 to 10mm in the mandible and 2.5 to 3.0mm in the maxilla. Similar results were found in other studies (Likeman et al., 1974; Douglass et al., 1993).

- **Rate of Loss**

The rate of reduction of the residual alveolar ridge has been shown to vary from individual to individual. It can also vary within the individual at different times or even within the jaws of that particular individual (Atwood, 1971). Longitudinal studies, which have followed patients between 5 and 25 years, have shown that this rate of loss follows a pattern. The residual ridge undergoes the majority of its remodeling and resorption during the first year after extraction (Crum et al., 1978; Carlsson et al., 1967; Carlsson et al., 1967; Atwood, 1971; Tallgren, 1972; Johnson, 1969), even up to two and a half years following extraction (Likeman et al., 1974). Following this period, the resorption process continues, but at a greatly slower rate. Continuing alveolar ridge reduction has been shown in studies of patients with 15-30 years of denture wearing experience. During a 24-month assessment period, denture wearers experienced about a 1.0mm reduction in the maxilla (Jackson et al., 1980). After 13 years of observation, experienced denture wearers lose about 8mm in the mandible and 2.2mm in the maxilla (Tallgren, 1972). This demonstrates how the residual ridge resorption can be considered an unlimited type of bone loss.

The mandible has been observed to resorb at a rate almost four times that of the maxilla (Tallgren, 1972; Atwood, 1971). The maxillary residual ridge has been shown to be relatively stable following tooth extraction. However, over 10 years bone height in the anterior region is reduced by 69% (Tuncay et al., 1984). Findings on the amount of bony reduction of the jaws seem to be greatly varied in the literature. In their longitudinal study, Atwood and Coy (Atwood et al., 1971; Carlsson et al., 1967) report an anterior height reduction of the mandibular residual ridge as 2mm on average over the first 6 months, with a total of 4mm after the first year of follow up. Tuncay et al (1984) show in their 10-year longitudinal study that the mandibular ridge is reduced by 2.14mm. Although the amount of bony reduction over time varies between different studies, the consensus is that the rate of resorption varies tremendously between the jaws.

- **Explanatory variables for alveolar ridge resorption**

Atwood describes the reduction of residual ridges as a consequence of several factors; hence it has been described as a multifactorial disease (Atwood, 1979). Many factors have been postulated to affect the rate and amount of ridge reduction, for example, face height, denture wear, retained roots, nutritional status, and prosthesis type worn. This study will focus on three important variables: sex, age and number of years of edentulousness.

Sex:

One of the factors thought to contribute to the residual ridge resorption is the sex of the patient. Osteoblastic function has been shown to differ between the sexes (Stepan et al., 1985). Thompson (1980) says that women experience a significant decline in bone mineral mass as compared to men. Men tend to maintain a constant activity while women tend to reach a peak around the age of 50-60, at which the activity subsequently decreases. Bone metabolism has been shown to be affected by hormone levels, such as estrogen. Once a woman reaches menopause, her estrogen levels are significantly altered, causing an increase in serum calcium and bone resorption. Men, at a comparative age, do not undergo such a drastic change in their hormone levels, which may explain their lower bone resorption (Sharpe, 1979). Due to this fall in hormone levels, women are at risk for developing osteoporosis. Osteoporosis is a degenerative bone disease that is more prominent in females than in males. In the early 1970's, it was thought to be a contributor in the multitude of factors that contribute to bone loss in edentulous ridges (Atwood and Coy, 1971). A literature review by Hildebolt (1997) revealed that radiographic analyses of the jaws have mixed results as to the effect of osteoporosis on the jaws. It is not known with certainty if dental osteopenia is a local manifestation of the systemic disease process of osteoporosis. However, the many studies reviewed by Hildebolt show that osteoporosis is an important factor to consider in residual alveolar bone loss. Aside from hormone levels, there are other important differences between the sexes that need to be considered.

The height of the residual ridge has been shown to be affected by the body mass index (BMI) of the individual (Klemetti et al., 1997) The BMI is defined as the weight (kg) divided by the height squared (m^2). The higher the BMI, the higher the residual ridge in the mandibles of edentulous women. Although this study did not compare the mandibular heights and BMI's of men to the study group, it can be postulated that this relationship may explain why men have been repeatedly shown to have more bone than women. Men have more bone in general than women do to begin with, which may influence the amount of residual bone left after resorption (Sharpe, 1979).

The literature has looked at the differences in the remaining alveolar ridge after extraction and varying results have been reported. Some investigators found no differences between the sexes in the amount of bone resorption (Soikkonen et al., 1996; Douglass et al., 1993; von Wowern et al., 1978; Tuncay et al., 1984). These studies indicate that the resorption occurs similarly between males and females. Most other studies however have shown trends that males have more residual bone than women. Atwood (1971) found men to have slightly higher rates of bone loss than women, but this finding was not statistically significant. Engstrom et al (1985) found that women had significantly less bone in the anterior and posterior segments of the mandible and in the anterior segment of the maxilla than men. Mercier and Lafontant (1979) found that men had higher values of ridge height than women. There are other studies that have shown sex differences specific to each jaw. Some have shown that there are no sex differences in the maxilla (Carlsson et al., 1967; Xie et al., 1997; Soikkonen et al., 1996). For von Wowern et al (1978), it was expected that women would have less bone than men because they have long been known to have more bone loss than men. Discrepancies in these studies may be attributed to the age range of the subjects used. The bone loss seen in females is generally not observed until around the fourth decade of life. This leads to another important cofactor in the determination of alveolar ridge height: the patient's age.

Age:

Age is an important factor to consider because many changes in bone occur over the lifespan of an individual. The balance between bone resorption and deposition varies depending on the stage of life. Children and adolescents tend to have more bone deposition, resulting in the growth of the skeleton. In adulthood, there is a coupling of formation and deposition so as to provide new bone tissue with no net loss in amount of bone. With advanced age, this linkage becomes uncoupled due to unelucidated reasons. Bone resorption begins to exceed bone deposition, resulting in a net loss of bone mass (Kiebzak, 1991). In addition, the rate of turnover of bone tissue is also diminished. This has been shown to result in a hypercalcification in the elderly (Kiobzak, 1991), an increase in the crystallinity of the bone (Matsushima & Hikichi 1989) and a decrease of mineral-associated proteins in bone (Dickson et al., 1985; Fisher & Termine, 1985). Hormones circulating in the body have also been shown to diminish with age. As was stated earlier, estrogen impedes parathyroid hormone (PTH) secretion, which acts as a protective mechanism against bone resorption. Over time, the negative feedback on PTH diminishes with the loss of estrogen, which results in an alteration in calcium homeostasis. Individuals experience a decrease in vitamin D_3, which, together with an increased PTH secretion, provides the proper conditions to favor bone resorption.

With all of this information on bone at hand, it would be easy to presume that with advancing age, one would expect to find a decrease in the amount of residual alveolar bone following extraction. Despite the state of metabolic activity in bone at a certain age, many studies which compared a young (<50 years) to an older group (>50 years) of individuals found no significant differences in the amount of alveolar ridge resorption (Carlsson et al., 1967; Soikkonen et al., 1996; Engstrom et al., 1985; Carlsson et al., 1967).

However, other studies have shown, that increasing age is related to bony changes in the mandible. Von Wowern and Stoltze conducted several studies on the relationship between age and mandibular bone mass and found that there is a significant decrease as age increases over 50 years (von Wowern et al., 1979; von Wowern et al., 1980; von Wowern et al., 1978). The mean cortical width of the bone was also shown to decrease while bone resorption activity increased (von Wowern et al., 1980). In a study that looked at bony architecture, they found that cortical porosity also increased with advancing age (von Wowern et al., 1978). Interestingly, studies done on the basal bone below the alveolar ridge have shown an increase in cortical thickness with advancing age (Lestrel et al., 1980; Xie et al., 1996). This may be due to the distribution of different loads that affect bone resorption and deposition. The exact cause still remains to be elucidated.

Years edentulous:

Residual ridge resorption has repeatedly been demonstrated to be continuous, irreversible and cumulative over time. For this reason, the amount of time since extraction is extremely important in predicting the amount of alveolar bone that remains. Many studies have focused on the amount of reduction with different types of dentures. However, it has also been demonstrated that resorption occurs in the absence of an oral prosthesis (Campbell, 1960). Once teeth are lost, the mechanical forces exerted on the ridges change. Denture wearing has been correlated with the severity of atrophy, presumably, due to loading pressures on the bony ridge (Zarb et al., 1997). Normal load on the ridge with complete dentition is about 44 pounds. It has been found that in patients with complete dentures, this load diminishes to 13-16 pounds or less (Zarb et al., 1997). As in bone in the rest of the body, the jaws undergo "disuse atrophy" as a consequence of diminished forces (Jahangiri et al., 1998). This disuse may even accelerate the bone turnover in the mandible (Devlin et al., 1991)

Since reduction is cumulative over time, it is expected that the longer the time since extraction, the less bone would remain in the ridge. Tuncay et al (1984) observed that this relationship is significant in the case of the mandible. Mercier and

Vinet (1981) also demonstrated the same statistical significance. Again, the literature does not indicate a specific trend. Some studies have indicated no significant difference (Xie et al., 1997), but found that women were edentulous longer than men. Atwood and Coy (1971) found a suggestive trend that longer denture wear could be associated with a greater reduction in the residual ridge. It is difficult to completely remove the factor of age and years edentulous because of the time factor. It is also difficult to separate the effect of age or time since edentulousness. New longitudinal studies are necessary in which individuals of different age groups having their teeth extracted at the same time.

The dental status of the opposing arch has also been shown to affect the residual ridge. When mandibular incisors oppose an edentulous maxilla, bite forces are directed through a maxillary denture towards the bone and cause bone loss in that region (Atwood, 1971). In other studies by Carlsson et al (1967, 1969), maxillary opposition to natural mandibular teeth was shown to be associated with a significant amount of resorption compared to a mandibular anterior prosthesis. Women, who have been edentulous for less than 30 years, have been demonstrated in a study by Klemetti (1995) to have ridge height that was significantly lower in the maxillae of those whose mandibular incisors were present longer.

- **Effect of ridge resorption on society**

For many years, the loss of all teeth was not considered as serious as the loss of a limb or an organ. This may be due to the fact that edentulousness is a very common, non-fatal condition in which treatment by conventional dentures was very common (Blomberg et al., 1983). The World Health Organization published the following definitions in 1980:

Impairment: Anatomical loss, structural abnormality or disturbance in biochemical or physiological processes which arises as a result of disease or injury or is present at birth.

Disability: Any limitation in or lack of ability to perform the activities of daily living.

Handicap: The disadvantage and deprivation experienced by people with impairments, functional limitations, pain and discomfort or disabilities because they cannot or do not conform to the expectations or the groups to which they belong.

(Locker, 1992)

Locker shows how edentulous individuals are now considered be physically impaired. They are also considered to be disabled because their condition limits their ability to perform the basic task of eating. Many individuals have reported that they experience trouble eating or speaking clearly (Albrektsson et al., 1987). In an edentulous population in Canada, about 38.7% could not eat some foods of their choice (Locker, 1992). Pain caused by dentures is also reported by about 30% of the edentulous population. They must then be considered to have suffered a loss equivalent to an organ and this has several implications (Albrektsson et al., 1987).

Edentulism is a very important issue in Quebec because of the large population of people who have lost all of their teeth. The Quebec rate of edentulism is the highest among all the provinces of Canada and is also higher than the national average (Brodeur et al., 1996) The distribution of edentate people does follow a trend. A survey done by Brodeur et al (1996) demonstrated that approximately 20% of the adult population of Quebec, aged eighteen and over were completely edentulous. These investigators also noted four factors that are associated with edentulism: the patient's age, level of education, level of income, and mother tongue. Age is the most important factor in determining risk of being edentulous. The highest percentage of edentate individuals (58%) is aged 65 and older. As well, people who have six years or less education, who earn $15 000 or less a year and whose mother tongue is French are most likely to be edentulous. Although Quebec has the highest rate of edentulism in Canada, the survey does indicate that the rate is on the decline. Thirteen years prior to this survey, the percentage of the adult population who had no teeth was six percent higher (Brodeur et al., 1996; Duquette et al., 1981).

- **Effect of ridge resorption on the individual**

Masticatory Difficulty

The stability of complete dentures relies heavily on the shape of the bone they were designed to fit. The denture does not change with the bone and, consequently, it becomes unstable. This mobility causes many problems, for example pain during mastication. The pain can be due to mucosal inflammation or ulceration from ill-fitting dentures, but this is only one source of masticatory difficulty. Due to bone resorption, the mental foramen may end up on the superior aspect of the ridge. Pressure on the inferior alveolar nerve emerging from the foramen is a major source of discomfort for people with this extensive resorption.

Previous studies have measured changes in edentulous patients' masticatory ability primarily through the use of patient-based questionnaires and laboratory methods using fractional sieving. For purposes of consistency, chewing ability will be defined as an individual's own assessment of his/her masticatory function. Chewing efficiency will be defined as the capacity to pulverize food during mastication, as measured by laboratory testing (Carlsson, 1984).

Surveys done to assess chewing ability have repeatedly shown that a good majority of complete denture wearers experience reduced capabilities. Some found that they cannot chew certain foods at all (Carlsson, 1984). Other studies that compare dentate, partially edentulous and completely edentulous people have found that as the number of missing teeth increases, chewing ability significantly decreases (Osterberg et al., 1982).

Chewing efficiency is usually measured by having the subject chew the food until they feel like swallowing. At that point, the subject is asked to spit the particles into sieves that separate them by size. These particles are then sized and weighed. In denture wearers, particles of food were found to be considerably larger than those produced by people with more teeth. There is a strong correlation found between the size of the particle and the number of molars the patients has (Oosterhaven et al., 1988).

Chewing efficiency has been used to measure the accuracy of findings in chewing ability studies. Patient-based outcomes have been considered by some to be "subjective". Therefore masticatory function has also been measured using laboratory tests ("efficiency"). Results from these laboratory efficiency tests suggest that many subjects over-rate their chewing ability. Many edentulous people report that they can eat many foods, but then perform poorly on test foods like almonds or carrots. However, this may be due solely to the fact that denture wearers may overcook or prepare the food differently (Carlsson, 1984). Tang et al (1999) have shown that the correlations between patients rating and laboratory tests of chewing function are poor and non-significant. They conclude that it is only the patient who can judge how well he/she can chew. Studies have also shown that the lack in capability of pulverizing food is compensated for by an increased amount of chewing strokes in denture wearers (Wayler et al., 1983). This was tested by observing the amount of strokes it takes for the subject to reach the swallowing threshold, or the point at which a person feels is the time to swallow their food (Wayler et al., 1983). Other studies have shown that some edentulous people do not bother to pulverize their food sufficiently and just swallow larger particles compared to dentate individuals (Oosterhaven et al., 1988). However, there is no evidence to show that the swallowing of larger particles causes problems.

Electromyography (EMG) is also used to assess the bite force during mastication. Denture wearers have been shown to have a substantially lower bite force than dentate individuals (Heath, 1982; Helkimo et al 1977). As well, EMG findings have shown differences in the activity of jaw closing muscles, especially the anterior temporal muscle, in denture wearers (Carlsson, 1984).

Speech Problems

Teeth are a vital part of our mechanism to elicit sounds or speech. When natural teeth are lost, so are the person's individual voice characteristics. Complete dentures replace the teeth, but affect the way many people form sounds and pronounce words. This is considered to be a problem among denture wearers (Misch et al., 1991).

The acoustic theory of speech states, "the modification of the vocal tract shape causes alterations of its acoustic output, i.e. of speech sounds production" (Fant 1960 in (Petrovic, 1985). The study done by Petrovic (1985) aimed to demonstrate the disturbance in speech that a prosthesis can cause. Patients were given sets of dentures in which the thickness of the incisors and palatal plate varied to evaluate the effect of longitudinal and horizontal dimensions of speech sounds, respectively. A mathematical method of measuring speech sounds indicated a sixty percent distortion when thickness was changed. In addition, this change influenced high frequency sounds and disturbed the harmony of sound in the test word. Increase in incisor thickness was shown to modify speech sounds by eighty percent when compared to a reference. These findings suggest that patients adapt their speech in relation to the form and thickness of the dentures.

Psycho-social Problems Associated with Denture Wearing

The hardships of edentulism and denture wearing just described ultimately contribute to the psycho-social problems that many of these people live with everyday. Some may find a smile to be a humiliating or anxious experience, when it is possible that a loose denture may fall out of place (Blomberg et al., 1983). Unstable dentures that cause pain have an impact on a person's sense of well being. According to the definition established by the World Health Organization, this decrease in self-assessed oral health constitutes a handicap.

Questionnaires that are employed to measure the psychological state of the edentate have shown that the decrease in masticatory function has led denture-wearing individuals to take more time to chew their food (Chen et al., 1984) and therefore, more time to finish a meal. Many people who responded to questionnaires have found this to be embarrassing. About 14 % of the population in a study done by Albrektsson (1987) also said that they avoided eating with others, which meets the WHO definition of having a handicap. Further investigation has shown that individuals compensate for this by swallowing less pulverized particles of food. In addition, compromised masticatory function detracts from the individual's ability to enjoy their food (Smith et al., 1979).

An edentulous person's self-esteem has been shown to be greatly influenced by the degree of comfort with their conventional denture (Berkey et al., 1985). Many live with a sense of insecurity or inferiority. Many patients never adapt to their prostheses and feel that their conventional dentures are foreign bodies. They are consequently always aware of their prostheses in their mouths. Surveys have shown that many people live in constant fear of losing their prostheses and being looked down upon (Albrektsson et al., 1987). One study suggests that dentures even detract from a person's quality of life (Heyink et al., 1986).

Studies have also revealed that ill-fitting dentures have contributed to the avoidance of social interactions by an edentulous person (Albrektsson et al., 1987). Many find it difficult to laugh with or kiss another person for fear of their dentures falling out. These people become self-conscious and insecure about themselves.

Some have admitted to being so insecure that they have kept their condition from their family members or even their own spouse (Albrektsson et al., 1987).

- **Treatment of edentulism**

Replacement of lost dentition in the completely edentulous can be done one of two ways: conventional dentures or implant supported prostheses. Conventional dentures are prosthetic devices that sit upon the residual alveolar ridge. Because of alveolar ridge resorption, problems arise with the use of these conventional dentures. This is why implants were developed and perfected over the last thirty years. Implants allow a solid interface on which a dental prosthesis can be placed. Both courses of action are in use today, each having their advantages and disadvantages.

Conventional Dentures

The most common method of replacing lost dentition is by the use of conventional dentures. Complete dentures come in three forms: conventional, immediate and overdentures. Conventional dentures are most commonly acrylic teeth set on an acrylic base molded to the shape of the residual ridge at the time of fabrication. Immediate dentures are those that are inserted immediately following tooth extraction. Overdentures are those dentures placed on top of the ridge containing endodontically treated dental roots. All three are constructed in a similar manner. The residual bony ridge and its accompanying mucosa support the dentures. In the maxilla, the hard palate offers an additional means of denture support. The edentulous individuals' ridges are evaluated through various modalities during treatment planning. In addition to an oral examination, radiographs must be taken in order to assess the state of the residual alveolar ridge. Extraoral radiographs, such as panoramic and lateral cephalographs, provide an adequate evaluation to the condition of the bony support. The thickness of the submucosa can also be approximated through radiography. Diagnostic casts of the patient's jaws are made and provide the dentist with an anatomical relationship of the patient's jaws in his/her absence.

A primary concern of any dental treatment is the total cost of the procedure to the patient. The cost of constructing complete dentures is relatively low and the technique fairly simple. Aside from the extraction of teeth, the use of conventional dentures requires very little surgical treatment. The healing period is limited to the time it takes for the sockets of the extracted teeth to fill and the mucosa to regenerate itself. This is advantageous to the patient in two respects: it keeps the trauma of dental surgery to a minimum and it keeps the cost of surgical procedures down as well.

The main drawbacks to the use of conventional dentures lie mostly on the consequences of alveolar ridge resorption. Since the dentures are moulded to the exact shape of the ridge at that specific moment in time, any change to the ridge would cause a problem in the dentures' exact fit. With the loss of bone, the denture becomes unstable. This has been associated with masticatory, speech and psychosocial problems, as was previously discussed.

Implant Supported Prostheses

With the discovery of the ability to integrate metal implants into bone, new options and alternatives could be offered to edentulous people. Implants are biocompatible (titanium) metal screws that are placed in the edentulous jaw. Upon healing, bone grows around the implant, creating a solid interface on which a dental prosthesis can be placed. Various types of fixed and removable prostheses supported by osseointegrated titanium implants can now be made. The implants significantly increase the stability of the prostheses, and patients report that chewing ability is substantially improved. Haraldson et al (1979) compared the chewing ability of dentate versus patients wearing implant-supported prostheses. They measured the ability to pulverize food and found chewing efficiency to be similar in both groups. The same results were found when chewing time, rate and the number of chewing strokes used before swallowing were measured. A similar study done by Carlsson et al in 1984 confirmed these findings. In addition, maximal bite force exerted during mastication increased, and the patient's own assessment of their ability to chew various foods greatly improved with osseointegrated oral implant bridges. This new stability allowed patients to feel more confident in themselves. In fact, patients perceived fixed dentures to be part of their body (Albrektsson et al., 1987; Blomberg et al., 1983). This improved comfort resulted in an increase in the patient's self-esteem, allowed them to make social contacts and even improve sexual relations. The patient has regained self-confidence.

Although patient satisfaction with implant-supported prostheses is highly rated compared to conventional dentures, implants do have some drawbacks. The main problems with implants relate to their cost, the trauma of the surgical procedure required to place them and the prerequisite amount of bone the patient must have prior to treatment.

The cost of diagnosis and treatment for implants exceeds those incurred during a conventional denture treatment. Prior to the treatment itself, the patient must undergo a clinical exam and various radiographic procedures. Panoramic radiographs are required to assess the height of the residual alveolar ridges, the quality of the alveolar bone and the presence of any abnormality. Lateral cephalographs can be taken to evaluate the width of bone on the midline of the jaws. These radiographic procedures are standard and also used for conventional denture planning. During implant preparation, depending on the amount of bone loss and location of the planned implants, the patient may require computed tomography of their jaws. In addition to being fairly expensive, this adjunctive imaging technique may not be accessible to some candidates in remote areas. Other costs the patient will have to endure are those for the implants themselves, the surgical insertion of the implants and the prosthesis to be placed on the implant. Implant-supported prostheses are more expensive than conventional dentures, particularly if they are the fixed-type.

The aim of this study is to determine whether a person's sex, age and how long they have been edentulous affect bone quantities, more specifically the height and width of the anterior alveolar ridge.

Materials and Methods

Patient Selection and Description of the Sample Population

The radiographs used in this study came from a previous study aimed to compare the satisfaction of a group of individuals who were exposed to two different types of implant-supported prostheses (de Grandmont et al., 1994). An advertisement was placed in La Presse, a daily newspaper in Montreal, Quebec, asking for men and women who were between the ages of 30 and 65 who had been completely edentulous for at least 10 years. The applicants also had to have problems with their existing maxillary prosthesis. Figure 1 displays a flow chart of patient selection. One thousand eight hundred and twenty eight people responded to the advertisement. Due to limitations of manpower only 819 patients were interviewed by phone. Three hundred and seventy one people were then asked to come to the clinic for the initial examination. One hundred eighty two people were then sent for further evaluation by panoramic radiographs and lateral cephalographs. Ninety-one of the 182 patients were sent for CT scans and finally 30 patients were accepted as candidates for four or more implants.

The following exclusion criteria were applied if their records did not contain the following information: date of birth, edentulous in the maxilla and in the mandible, the patients' age, sex, and the panoramic radiograph and/or lateral cephalograph. Of the 182 patients who were sent for further radiographic evaluation, 90 people still had the panoramic radiographs in their files and 78 patients had lateral

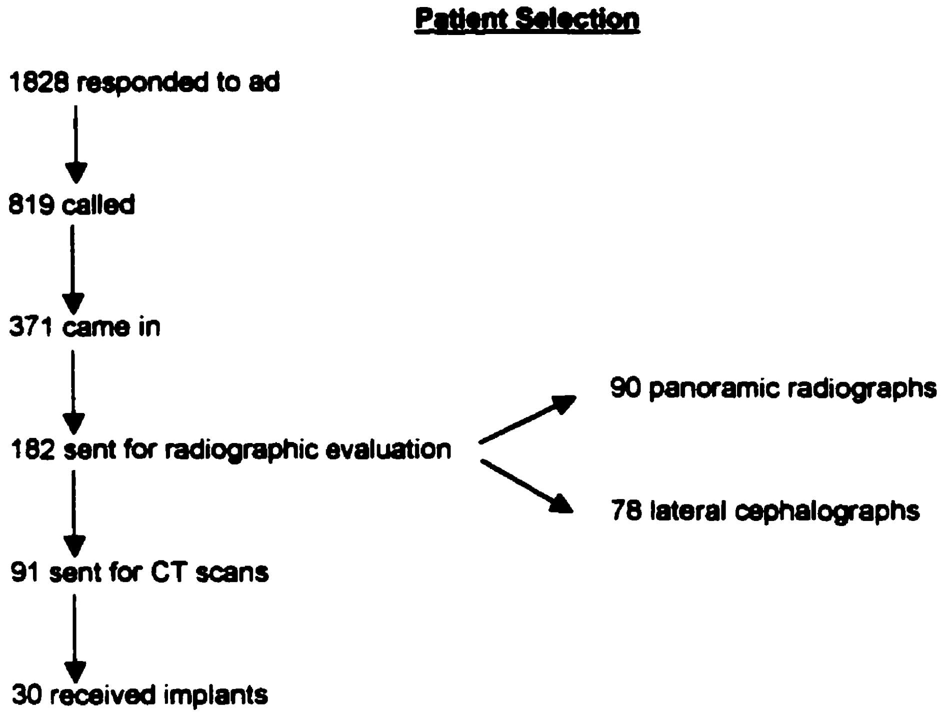

FIGURE 1

cephalographs. From the 182 patients sent for further evaluation, 95 had a panoramic radiograph, lateral cephalographs or both.

The age of the patients ranged from 29 to 63 years. People were edentulous in the maxilla for 7 to 42 years and in the mandible for 8 to 42 years. The mean age of the sample was 46 years. On average the sample was edentulous in the maxilla for 24 years and in the mandible 23 years. Most individuals had lost all of their teeth at the same time. Twelve people lost their maxillary teeth first while 5 people lost their mandibular teeth first.

In the sample population of this thesis (n=95), there were 44 males and 51 females. The age range of the males was between 30 to 63 years of age, with a mean age of 46 years. The men were edentulous for about 23 years on average in the maxilla (range 10 to 42 years) and about 22 years in the mandible (range 10 to 42 years). The females in the study had a mean age of 46 (ranging from 30 to 63 years). The women were edentulous for about 25 years on average in the maxilla (range 7 to 40 years) and about 24 years in the mandible (range 8 to 39 years). Because the sample size was small, age and years edentulous in both jaws were made categorical in order to augment the effect of each variable. Each was categorical into two groups that were separated by the median of each variable. Therefore, the categories were <45 and ≥45 years for age, <21 and ≥21 years for years edentulous in the mandible, and <22 and ≥22 years for years edentulous in the maxilla.

Methods of Measurement

Determination of bone height:

Bone height was defined two ways in this thesis. In the maxilla, it was the measurement of the height of bone between the hard palate and the most inferior aspect of the ridge at the location of the most lateral position of the nasal cavity wall. In the mandible, it was defined as the measurement between the most inferior limits of the mandibular cortex to the most superior limit of the residual alveolar ridge located at the medial side of the mental foramen. These measurements were taken

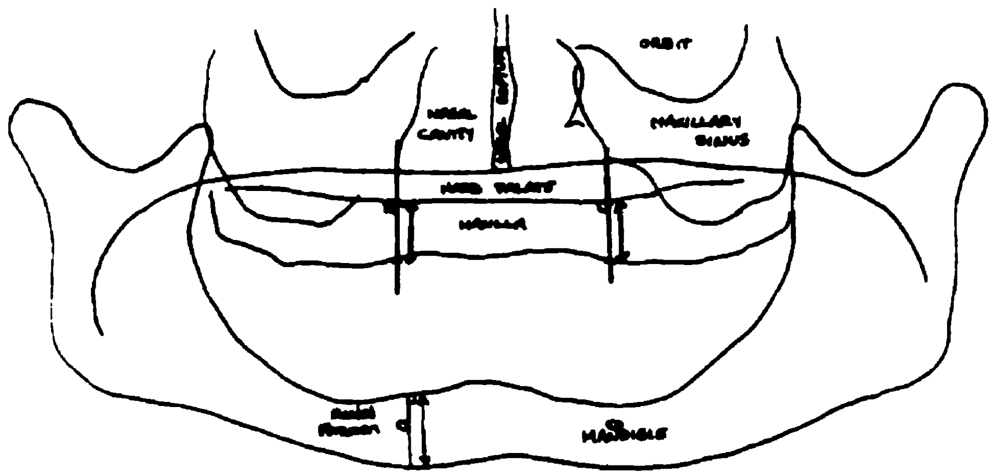

FIGURE 2

on panoramic radiographs (figure 2). Panoramic radiographs were taken using a Planmeca PM 2002 CC (Helsinki, Finland).

For the maxilla, points of reference had to be established. A point on the most lateral aspect of the nasal cavity was established. A line was then extrapolated inferiorly so that the line was perpendicular to the most superior aspect of the hard palate. The height measurement was taken on this line, between the point on the hard palate and the most inferior aspect of the residual alveolar ridge. This was repeated on the opposite side.

In the mandible, three measurements were taken: one on each side and at the midline. For each side, the most medial aspect of the mental foramen was established. Wical and Swoope (1974) used a similar method in their studies on mandibular resorption and found this location to be reliable. A line, which was perpendicular to the inferior border or the mandible, was extrapolated. The height of the bone was measured between the superior and inferior ridge on the mandible on this line. The middle measurement was done on the midline between the superior edge and the inferior edge of the mandible.

Determination of bone width:

Bone width, in this thesis, is defined as the measurement of the width of the anterior residual alveolar ridge as seen in a profilar view on a lateral cephalograph. The lateral cephalographs were taken using the Picker GX-300 (Bramalea, Ontario). See figure 3. On the maxilla, two landmarks were determined: the anterior nasal spine and the point at which the posterior wall of the maxillary sinus meets the most superior aspect of the hard palate. These two points were then joined to form the first reference line. The most inferior point on the maxillary residual alveolar ridge was then established. This point was then joined to the first reference line with a perpendicular line. This is the second reference line. This line is measured and

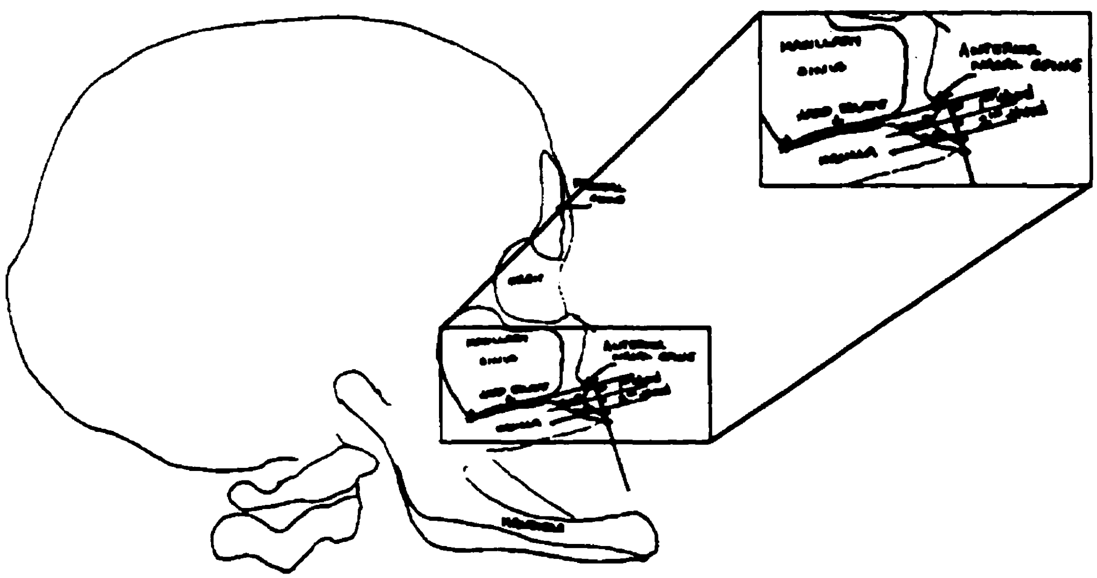

FIGURE 3

divided into thirds. Each third was placed on the second reference line, counting from the top. At each third, a parallel line to the first reference line was drawn. The width of the bone is then measured on this line. Using these techniques, we obtained two measurements from each patient.

Determination of the bone shape:

The CT scans were used to determine the shape of the maxilla. The CT scanner used was the Chimadzu SCT7000TH (Japan). The axial scans consisted of 2mm slices with 2mm table increments in the axial plane were done in the region of the maxilla on ninety-one patients. Reformatted images were done at three anterior regions on the maxilla: at the midline and one on either side of the midline at

BONE SHAPE CLASSIFICATIONS

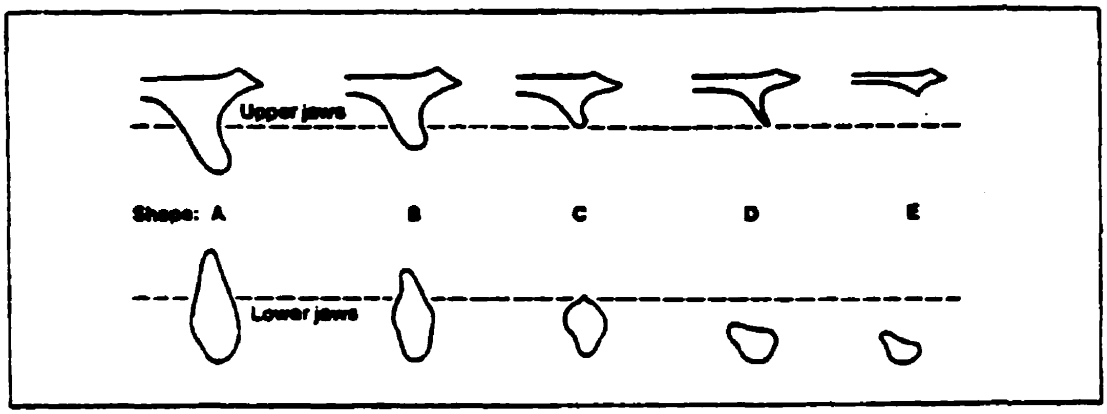

FIGURE 4

approximately the canine region. Of the ninety-one patients with CT scans, only 53 were used due to missing information or reconstructions. A student and a radiologist traced the bone shapes with a Staedtler fine-tipped permanent marker (Nuremberg, Germany) on 3M overhead transparencies (St. Paul, Minnesota) placed over the scans. To ensure correct placement of the sheet at any time, two holes, the same distance apart, were punched in both the overhead transparency and the CT scan.

Using the reconstructed image at the level of the canine region, three trained examiners classified the maxillary tracings according to those described by Lekholm and Zarb (Lekholm et al., 1985) (figure 4). The three examiners classified the tracings twice at a three-day interval. First, the reliability of the tracings was tested between the student and a radiologist. Secondly, the correlation was used to test the reliability between and within two raters, a dentist and a dental radiologist for the classification of the tracings according to Lekholm and Zarb. Because the sample population was small, it was decided to analyze the tracings by grouping those tracings classified A/B as class 1 and those marked C/D/E as class 2. Using the radiologist's classification, a Chi-Square test was used to analyze the relationship of the two classes to sex and age. Since the number of subjects was inadequate for a Chi-square, a Fisher's Exact test was performed to analyze years edentulous to shape class.

Statistical Analysis

The statistical packages Systat 7 (SPSS Science, Chicago, Illinois) and SAS/STAT (SAS Institute, Cary, North Carolina) were used to perform the statistical analysis. The independent variables included patient age, sex, years edentulous in the maxilla, and years edentulous in the mandible. The dependent variables were bone height in the maxilla, bone height in the mandible, bone width in the maxilla.

Bone width and height were analysed for preliminary correlations using the Student's t-test to compare categorical data to continuous data. Multiple linear regression was used to compare all of the independent variables to the dependent variables.

Bone Shape tracings were tested for inter-rater and intra-rater reliability using analysis of variance. The radiologist traced a sub-sample of CT scans. The tracings were scanned into a computer by means of a Hewlett Packard 4C scanner. The images were then analysed using the software Image Pro Plus (Media Cybernetics, Silver Spring, Maryland). The areas depicted by the tracings were measured and correlated. The categorization of the tracings was also tested for reliability between and within three examiners. Statistically, the reliability of classification within the examiner and between examiners was evaluated using intraclass correlation (ICC).

Results

Mandible:

- Bone Height:

Table 1 displays the results of the univariate analysis done for bone height in the mandible. The two-tailed t-test showed significant effects of years edentulous in the mandible ($p=0.04$) and maxilla ($p=0.001$), sex ($p<0.0001$), and age ($p=0.03$). Multiple regression tests, as shown in table 2, revealed an effect from only two variables, the years edentulous in the maxilla ($p=0.003$) and sex ($p<0.0001$).

TABLE 1:
UNIVARIATE REGRESSION ANALYSIS: HEIGHT IN THE MANDIBLE

Variable	Parameter Estimate	95% Confidence Interval	P-Value
Yrs. Edent. Max.	0.477	0.199 to 0.755	0.001
Sex	-0.739	-0.992 to -0.486	0.000
Age	0.326	0.038 to 0.614	0.027
Yrs. Edent. Mand.	0.304	0.014 to 0.593	0.04

TABLE 2:
MULTIVARIATE REGRESSION ANALYSIS: HEIGHT IN THE MANDIBLE

Variable	Parameter Estimate	95% Confidence Interval	P-Value
Yrs. Edent. Max.	-0.561	-0.991 to -0.231	0.003
Sex	-0.718	-0.956 to -0.480	0.000
Age	-0.081	-0.367 to 0.212	0.57
Yrs. Edent. Mand.	0.205	-0.151 to 0.620	0.277

R^2=0.387; P<0.0001 for the model
Reference groups: age:<45 years; sex: F; Yrs edentulous maxilla: <22 years; Yrs edentulous mandible: <21 years

Maxilla:

- Bone Height:

Table 3 displays the results of the univariate analysis done for bone height in the maxilla. In the t-tests comparing bone height in the maxilla to each of the independent variables, there were no significant values obtained. However, when all the variables were analyzed together in the multiple linear regression model, the time since edentulousness in the maxilla had significant effect on the bone height in the maxilla (p=0.004). Furthermore, there was a tendency for years edentulous in the mandible to be associated with bone height (p=0.076). This is shown in Table 4.

TABLE 3:
UNIVARIATE REGRESSION ANALYSIS: HEIGHT IN THE MAXILLA

Variable	Parameter Estimate	95% Confidence Interval	P-Value
Yrs. Edent. Max.	0.134	-0.036 to 0.304	0.122
Sex	-0.049	-0.222 to 0.124	0.575
Age	-0.087	-0.260 to 0.086	0.318
Yrs. Edent. Mand.	-0.26	-0.197 to 0.151	0.795

TABLE 4:
MULTIVARIATE REGRESSION ANALYSIS: HEIGHT IN THE MAXILLA

Variable	Parameter Estimate	95% Confidence Interval	P-Value
Yrs. Edent. Max.	-0.37	1.110 to 2.008	0.004
Sex	0.065	-0.062 to 0.287	0.445
Age	0.157	-0.036 to 0.368	0.11
Yrs. Edent. Mand.	0.231	-0.049 to 0.482	0.076

R^2=0.114; P=0.044 for the model
Reference groups: age:<45 years; sex: F; Yrs edentulous maxilla: <22 years; Yrs edentulous mandible: <21 years

- Bone width:

The results of the univariate analyses for bone width at the first and second third of the anterior maxilla are illustrated in Table 5 and 6. No significant effect was shown by a t-test comparing bone width with maxilla/mandible years edentulous, sex and age. In the multivariate analyses, a different picture arises. The difference in means of the width of the first third between the two categories of years edentulous in the maxilla is significantly different ($p<0.05$).

TABLE 5:
UNIVARIATE REGRESSION ANALYSIS:
WIDTH (FIRST THIRD) IN THE MAXILLA

Variable	Parameter Estimate	95% Confidence Interval	P-Value
Yrs. Edent. Max.	0.073	-0.099 to 0.244	0.408*
Sex	-0.116	-0.286 to 0.054	0.178
Age	-0.051	-0.224 to 0.121	0.555
Yrs. Edent. Mand.	-0.041	-0.214 to 0.132	0.638

* See Multivariate Regression Analysis

TABLE 6:
UNIVARIATE REGRESSION ANALYSIS:
WIDTH (SECOND THIRD) IN THE MAXILLA

Variable	Parameter Estimate	95% Confidence Interval	P-Value
Yrs. Edent. Max.	0.067	-0.033 to 0.167	0.188*
Sex	-0.018	-0.119 to 0.083	0.727
Age	-0.063	-0.164 to 0.037	0.214
Yrs. Edent. Mand.	-0.037	-0.138 to 0.064	0.467*

* See Multivariate Regression Analysis

Table 7 and 8 refer to the multivariate statistical analyses for the width of the residual alveolar ridge of the anterior maxilla. The width of the first third of the maxilla is significantly related to the number of years edentulous ($p<0.05$) and there is a tendency for the years edentulous in the mandible to be associated with the maxillary width ($p<0.10$). In the second third, the width was found to be significantly associated with the two categories of years edentulous of the maxilla ($p=0.001$). As well, it was found that the number of years edentulous in the mandible has a significant effect on the width of the second third ($p<0.05$).

TABLE 7:
MULTIVARIATE REGRESSION ANALYSIS:
WIDTH (FIRST THIRD) IN THE MAXILLA

Variable	Parameter Estimate	95% Confidence Interval	P-Value
Yrs. Edent. Max.	-0.296	-0.573 to -0.019	0.036
Sex	0.127	-0.042 to 0.297	0.138
Age	0.038	-0.170 to 0.247	0.714
Yrs. Edent. Mand.	0.268	-0.034 to 0.569	0.082

R^2=0.087; P=0.153 for the model
Reference groups: age:<45 years; sex: F; Yrs edentulous maxilla: <22 years; Yrs edentulous mandible: <21 years

TABLE 8:
MULTIVARIATE REGRESSION ANALYSIS:
WIDTH (SECOND THIRD) IN THE MAXILLA

Variable	Parameter Estimate	95% Confidence Interval	P-Value
Yrs. Edent. Max.	-0.265	-0.422 to -0.109	0.001
Sex	0.025	0.041 to 0.382	0.603
Age	0.069	-0.049 to 0.187	0.25
Yrs. Edent. Mand.	0.211	-0.071 to 0.121	0.016

R^2=0.154; P=0.015 for the model
Reference groups: age:<45 years; sex: F; Yrs edentulous maxilla: <22 years; Yrs edentulous mandible: <21 years

- Bone Shape:

The analysis of variance showed that the areas of the tracings between the student and the radiologist were 98% reliable.

Classification reliability, as tested using intraclass correlation, showed that within raters, there is variability in the level of reliability. Individually, the radiologists had the highest reliability of 87% and the dentist scored a 38%. An analysis of the ICC between raters brought the reliability of the classification to 36%.

The Fisher's exact test revealed that there were no significant tendencies to be in a particular age, sex nor years edentulous between class 1 or 2 (probability=1).

Discussion

The purpose of this study was to address three hypotheses.

1. Do sex, age, and years edentulous influence the amount of alveolar ridge height in the anterior maxilla and mandible?
2. Do sex, age, and years edentulous influence the amount of alveolar ridge width in the anterior maxilla?
3. Do sex, age, and years edentulous influence alveolar ridge shape in the anterior maxilla?

Relationship of amount of bone to sex, age and years edentulous:

- Mandibular alveolar bone height

When all the dependant variables were factored into the statistical analyses, the multiple regression tests revealed a significant effect of sex ($p<0.0001$) on the amount of residual alveolar bone height in the anterior mandible. Males had more bone height in the mandible. The correlation between gender and degree of resorption has been shown on repeated occasions (De Baat et al., 1993; Engstrom et al., 1985; Friedman et al., 1985; Soikkonen et al., 1996; Xie et al., 1997). The many women in this study were of a menopausal or postmenopausal age. The estrogen deficiency in menopause can accelerate skeletal bone loss and may result in the higher residual ridge resorption found in females. One author has found that females have lower values than men, but the difference was not significant (Carlsson et al., 1967). The results found in this study, however, are based on values of bone height and width at the moment in time when the radiographs were taken. Klemetti et al (1997) have discussed that individuals with a higher BMI tend to have higher residual ridges than those with a lower BMI. Men generally have more bone than women (Sharpe, 1979). In the study population of this thesis, the BMI's between the male and female subjects were not compared nor could it be determined if the two sexes started off with the same amount of bone. Therefore, the significant difference we have found may be due to a decreased rate of resorption in males or to the same rate of resorption between the sexes, but the women started off with less bone.

Years edentulous in the maxilla were also found to have a significant effect ($p=0.003$) on the amount of bone height in the mandible in this study population. People who were edentulous longer in the maxilla had more bone than those who have been edentulous for a shorter period of time. This is consistent with findings in another study (Klemetti et al., 1994). This study also demonstrated that the presence of natural maxillary teeth causes more residual ridge resorption in the trabecular bone on the mandible than a conventional denture.

Years edentulous in the mandible were not found to be a significant factor in the height of mandibular bone in this study population. It would be expected that the longer the years of edentulism, the less the height of bone. Some studies have shown a correlation between the degree of resorption in the mandible and the number of years dentures are worn (Carlsson et al., 1967; Tuncay et al., 1984). In longitudinal studies, it was shown that the rate of loss slows down after a prolonged period of time since extraction (Tallgren, 1972). This may explain the findings of this thesis since all the subjects were edentulous for an average of 24 years. The exclusion criteria formulated to collect these data in the original study required the study population to have had at least 10 years edentulous experience. This could mean that the degree of resorption for these individuals had already slowed down so that no difference could be seen.

Age was also shown to have no significant effect on the anterior mandibular alveolar ridge. This is consistent with the findings in other studies (Atwood et al., 1971; Engstrom et al., 1985; Carlsson et al., 1967).

- Maxillary alveolar bone height and width

Statistical tests of the data show that there were significant effects of maxillary years edentulous on anterior maxillary bone width in the upper third ($p<0.05$) and in the lower third ($p=0.001$). The analyses of the maxilla also revealed that years edentulous in the maxilla had a significant effect on the bone height ($p=0.004$). It would be easy to say that this is an expected result because of the logical thought that bone loss occurs over time. The longer one's experience without teeth, the more bone loss there should be. However, the literature has repeatedly shown the opposite (Klemetti, 1995; Jackson et al., 1980; Xie et al., 1997). Most of the bone loss occurs in the first few months following the extraction. The sample population in this thesis study had been edentulous in the maxilla for an average of 24 years and no less than 10 years. Watt and Likeman found that the most rapid and significant changes occur within the first year following extraction (Watt & Likeman, 1974).

After bony healing, the bone loss in the maxilla slows down considerably, about one quarter the rate of the mandible, leading to insignificant bone loss even over 20 years (Tuncay et al., 1984).

Sex was shown to have no effect on the anterior maxillary alveolar ridge width or height. This is in agreement with several studies in the literature (Xie et al., 1997; Nedelman et al., 1978; Morgan et al., 1969; Soikkonen et al., 1996; Douglass et al., 1993; Xie et al., 1997). Both men and women experience bone loss with age. In women, the loss of bone usually begins between 35-45 years of age and in men between 45-65 years. This study involved people who were, on average, well into the ages where bone loss occurs. The hard palate allows the maxilla to be very resistant to resorption, especially many years following extraction (Tallgren, 1972) and it seems to be the same between the sexes (Likeman et al., 1974). Engstrom et al (1985) have shown, however, that women had a significantly lower anterior alveolar bone height in a study population that had been edentulous for at least ten years. Their sample had many more female subjects than men that may have contributed to this finding.

Age did not have a significant role in the amount of residual alveolar bone in the maxillae of this thesis study population. This may be attributed to the fact that all the subjects had at least 10 years edentulous experience. Bone resorption had probably leveled off by this stage. Other studies done under similar conditions have come to similar conclusions (Soikkonen et al., 1996; Kalk et al., 1989).

Mandibular edentulism was shown to have a significant effect on width in the lower third of the maxillary ridge ($p<0.05$). Atwood (1971) reported that when mandibular incisors oppose an edentulous maxilla, bite forces are directed through a maxillary denture towards the bone and cause bone loss in that region. Carlsson et al have also demonstrated that maxillary opposition to natural mandibular teeth was associated with a significant amount of resorption compared to a mandibular anterior prosthesis (Carlsson et al., 1967; Carlsson et al., 1969). Mandibular edentulism had no significant effect on maxillary bone height. This could possibly be explained by the fact that most of the thesis' sample population lost the teeth in both their jaws at approximately the same time (Xie et al., 1997). In this sample, only a few had time discrepancies in years edentulous in the maxilla and mandible. This does not agree with findings that Atwood describes in a study done in 1971. Klemetti (1995) has shown in one study that this holds true for women who have been edentulous for less than 30 years. Ridge height was significantly lower in the maxillae of those whose mandibular incisors were present longer.

- Maxillary alveolar bone shape

Because there were differences in the magnification of the reconstructed CT images between patients, a qualitative, as opposed to quantitative, study was performed. The results revealed that there was reliability between the two observers, a student and oral radiologist. It was concluded that minimal training is required in order to trace the shape of the alveolar bone on CT scans.

The attempt at categorizing the tracings of the alveolar ridges into the classification of Lekholm and Zarb (1985) was unsuccessful. There was a wide discrepancy between the observers. The "non-expert" had a very low reliability. Classifications of the tracings were not consistent between the observers. It was therefore concluded that a certain level of expertise is required to classify the shape of the alveolar bone into defined categories.

In Lekholm and Zarb's classification system, class A and class B are very similar. Class C, D, and E, representing more advanced bone resorption, are alike in shape and differ only in quantity of remaining bone. Because the sample population was small, it was decided to analyze the tracings by grouping those tracings classified A/B as class 1 and those marked C/D/E as class 2. Using the radiologists's classification, a Chi-Square test was used to analyze any tendencies within the two classes. The statistical tests revealed that neither group had significant tendencies to be in a particular age or sex. When studying the relationship between the classes of shape and years edentulous, a Fisher's exact test was used. However, no significant associations were detected. Perhaps a larger sample size may be needed in this case to determine statistical significance. The results may also be affected by the choice of the study population. The patients who received the CT examination had panoramic radiography and lateral cephalographic examinations to determine adequate bone for implants. They had to show sufficient amounts of bone on the films to receive a CT examination, and patients with more severe bone loss did not receive it. Therefore, all subjects in this study began with non-severe bone loss.

Limitations of the study

- Study population

As Atwood and others in the literature have shown, the reduction of residual ridges is a multi factorial disease. From the information available, this study was able to look at the relationship of some important factors, such as sex, age and years edentulous to the alveolar bone (Atwood and Coy, 1971). Other important factors, which may affect amount of residual bone, have been demonstrated in the literature such as: local and systemic factors (Atwood, 1979; Atwood et al., 1971; Baylink et al., 1974), environmental factors (Klemetti et al., 1997), or race (Benson et al 1991; Lavelle, 1960).

- CT scans

The CT scans were printed on film and acquired before the conception of this study. The number of reformatted images was limited. The variation in size of the reformatted image complicated the classification of bone shapes. There were as many as 17 different magnifications of the images. This may have interfered with the rater's ability to classify the shapes of the alveolar bone correctly and resulted in the low reliability scores.

Another problem involving the testing of the third hypothesis is that even though the radiologist had high reproducibility of the classification, it was not tested, either through this study or in the literature, to see if the classification system proposed by Lekholm and Zarb is valid. The resources available to this study were inadequate to allow for this kind of test. As well, because the data were collected prior to this study, some information pertinent to the statistical analysis were missing or lost, resulting in the exclusion of patients and reduction in sample size.

- Radiographs

Measurements were done directly on radiographs. For the most part, landmarks pertinent to this study were clearly visible. However, there were some instances when the dental radiologist could not even definitively locate them. Because of the retrospective nature of the data, it was impossible to recall patients for radiographic retakes (Lavelle, 1960).

Future Studies

Future studies could include testing the validity of a classification system like that of Lekholm and Zarb, as well as testing its reliability in a clinical setting. Testing of the reliability between or within prosthodontists could be done by repeated classification of patient scans according to the categories established by this study. Since it is well accepted that residual ridge resorption is a multi factorial disease, future studies could include other independent variables, such as race, local, systemic, and environmental factors.

Conclusions

The purpose of this study was to address three hypotheses:

1. Do sex, age, and years edentulous influence the amount of alveolar ridge height in the anterior maxilla and mandible?

This study found significantly greater amounts of mandibular residual alveolar bone in males and those with more edentulous years in the maxilla. In the maxilla, there were significantly greater amounts of residual alveolar bone in those who were in the younger maxillary edentulous years category.

2. Do sex, age, and years edentulous influence the amount of alveolar ridge width in the anterior maxilla?

Statistical analysis showed significant associations were found when comparing maxillary and mandibular years edentulous to anterior maxillary bone width.

3. Do sex, age, and years edentulous influence alveolar ridge shape in the anterior maxilla?

Statistical analysis of this study population revealed no significant associations between sex, age, and years edentulous and anterior maxillary bone shape.

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