ALMA MATER STUDIORUM

UNIVERSITÀ DI BOLOGNA

DOTTORATO DI RICERCA IN

BIODIVERSITÀ ED EVOLUZIONE

XIX CICLO

IMAGE ANALYSIS IN THE MORPHOLOGICAL AND MORPHOMETRIC STUDY OF TEETH

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BIO/08

ESAME FINALE, 2007

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DISSERTATION ABSTRACT

The subject of this doctoral dissertation concerns the definition of a new methodology for the morphological and morphometric study of fossilized human teeth, and therefore strives to provide a contribution to the reconstruction of human evolutionary history that proposes to extend to the different species of hominid fossils. Standardized investigative methodologies are lacking both regarding the orientation of teeth subject to study and in the analysis that can be carried out on these teeth once they are oriented. The opportunity to standardize a primary analysis methodology is furnished by the study of certain early Neanderthal and preneanderthal molars recovered in two caves in southern Italy [Grotta Taddeo (Taddeo Cave) and Grotta del Poggio (Poggio Cave), near Marina di Camerata, Campania]. To these we can add other molars of Neanderthal and modern man of the upper Paleolithic era, specifically scanned in the paleoanthropology laboratory of the University of Arkansas (Fayetteville, Arkansas, USA), in order to increase the paleoanthropological sample data and thereby make the final results of the analyses more significant. The new analysis methodology is rendered as follows:

1. Standardization of an orientation system for primary molars (superior and inferior), starting from a scan of a sample of 30 molars belonging to modern man (15 M1 inferior and 15 M1 superior), the definition of landmarks, the comparison of various systems and the choice of a system of orientation for each of the two dental typologies.
2. The definition of an analysis procedure that considers only the first 4 millimeters of the dental crown starting from the collar: 5 sections parallel to the plane according to which the tooth has been oriented are carried out, spaced 1 millimeter between them. The intention is to determine a method that allows for the differentiation of fossilized species even in the presence of worn teeth.
3. Results and Conclusions. The new approach to the study of teeth provides a considerable quantity of information that can better be evaluated by increasing the fossil sample data. It has been demonstrated to be a valid tool in evolutionary classification that has allowed (us) to differentiate the Neanderthal sample from that of modern man. In a particular sense the molars of Grotta Taddeo, which up until this point it has not been possible to determine with exactness their species of origin, through the present research they are classified as Neanderthal.

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FIRST PART

INTRODUCTION

Fossils are the direct witnesses of ancient living organism or their ancient tracks, and studying them gives us the possibility to open a window toward the past. For this reason it is necessary to find the best method for analyzing them. Furthermore different fossils allow us to obtain different information, and in general some of them are more important than others. This depends in part on the size of the fossil fragment and mainly on the kind of skeletal remains discovered. In a particular way, teeth are one of the most important fossils in paleontological field for their particular physical-chemical characteristics: usually they are less involved in the diagenetic processes versus the bones. For this reason phylogenetic reconstruction of human evolution is often based on dental remains. Traditional approaches for studying skeleton or dental remains are characterized by their morphological descriptions and morphometric measurements by means of specifically anthropometric instruments. Nevertheless in traditional approach morphological and morphometrical analyses are sometimes overly subjective, and some careless mistakes and systematic errors due to the instruments are often involved.

In this research a different approach for morphological and morphometrical tooth analysis based on three-dimensional image analysis has been standardized. Three molar teeth, discovered in two different caves located in South Italy (Taddeo Cave and Poggio Cave) and chronologically related to a late phase of the human evolution, have been considered. The uncompleted taxonomic evaluations obtained for these teeth using a traditional approach, have inspired us to develop a different, more objective approach which permits us to obtain more information of the tooth under investigation providing a useful contribution for the philogenetic reconstruction of human evolution. Due to this, the dissertation is divided in two parts. In the first part a detailed description of the traditional anthropological approach for tooth analysis is reported. Subsequently, further information is provided about present developments of the research in two-dimensional and three-dimensional approach.

In the second part all the different phases that characterize the new methodology are explained. The lack of a virtual three-dimensional molar sample has required a three-dimensional scan of some Modern Human and Neanderthal molars and the resolution of some new different problems. Finally, on the bases of this virtual three-dimensional sample and the creation of the new methodology, the molars of Taddeo Cave and Poggio Cave have been analyzed. The good results obtained in this research provide a starting point for further developments of the new methodology.

CHAPTER 1

1.1 PHYSICAL-CHEMICAL CHARACTERISTICS OF THE TEETH

It wouldn't be significant to provide a detailed description of the features of the teeth, considering that many specific dental anthropological manuals exist in the scientific literature (Ash, 1986). However, some information could be necessary for better understanding the most significant parts of this research, and at the same time for acquiring specific words constantly used in the following pages.

In this way it will be easier to understand the limits of the traditional approach for studying teeth, the doubts and the attempts for improving this restrictive situation, and finally for looking at our choices in a sympathetic way.

In regards to the particular physical-chemical features, teeth are different from bones. In general, a tooth is characterized by two parts: the root (that is located in an apposite socket of the alveolar process of the jaw), and the crown (protruding from the alveolar socket, holding an active role in the masticatory process).

The crown is made of two tissues: dentin and enamel. The dentin closes inside the pulpal chamber and it is made of two parts: an inorganic part very similar to bone, and an organic part in which collagen prevails and, in less quantity, protein elements are present.

The enamel is a hard mineralized coating that covers the dentin. It is made of two parts: an inorganic (apatite) and organic part (lipids and protein wastes).

Also the root is made of two tissues: dentin in the interior part (it covers the root portion of the pulpal chamber), and cement outside. Cement is a tissue not only less compact than the enamel but also the dentin as well. It is principally made of mineral elements (calcium, phosphate, etc...), but also fair quantity of collagen and water are present.

The cervical line (cement/enamel junction) is the area where the crown and root join together.

Finally, in the pulpal chamber the dental pulp is contained, in which vessels and nerves are present.

1.2 TOOTH MORPHOLOGY

In general we can distinguish anterior teeth (incisors and canines), and posterior teeth (premolars and molars). Even if specific typology of teeth are identified (incisor, canine, premolar and molar), each tooth has an irregular shape. However, fundamental rules have been defined. Teeth have five principle faces:

1. the vestibular or buccal face: generally called “labial face” for incisors and canines (it means the side of the tooth facing the lips), whilst the “vestibular face” or “buccal face” for molars and premolars;
2. the lingual face: the side of the tooth facing the tongue;
3. the mesial face: it is one of the inter-proximal faces and is the side of the tooth facing the median line; it always joins the distal face of the preceding tooth, except for the first incisor where the two mesial faces of each first incisor join together;
4. the distal face: the other inter-proximal face, is the side of the tooth facing the back of the mouth; while in M3 (third permanent molar) and m2 (second deciduous molar) this face is free, in the other cases it joins the mesial face of the following tooth;
5. the surface of the crown: it is usually called the “occlusal surface” in molars and premolars because it occludes with the “occlusal surface” of the opponent molar; it becomes an edge on the incisor and a double edge on the canine.

For tooth description, the crown and the root are separated in three approximately equal longitudinal parts and correspondingly as many equal transversal parts. These parts take different names in relation to the specific position they have.
Considering the transversal parts we can distinguish:

1. the incisal or occlusal part, respectively for anterior and posterior teeth;
2. the middle part;
3. the cervical part.

Concerning the longitudinal subdivision, we can distinguish a bucco/lingual aspect and a mesio-distal aspect. The three parts for the bucco/lingual aspect are: labial or buccal, middle and lingual part; instead for the mesio/distal aspect are: mesial, middle and distal part. The root is also separated in three equal transversal parts: respectively cervical, middle and apical parts.

1.2.1 THE CROWN

On the crown of the tooth different features are usually recognized. We might define some of them as “positive features”, while others are “negative features”. Both of them are very important for morphological description and morphometrical analysis of the teeth. Positive features take different names in relation to the location and the dimension they have in the crown:

- cusp: a prominence of variable dimension positioned on the occlusal surface of the tooth;

- tubercle: an atypical bulge of variable size that growths in the crown surface except in the occlusal surface;
- cingulum: a characteristic swelling of the anterior teeth positioned in the lingual face near the cervical line;
- crest: considering the position in the crown it takes specific names. We speak about "marginal crest" if they delimit the mesial and distal edge of the crown, or "triangular crest" when in the occlusal face of the posterior teeth relief growths occur in the internal side of a cusp. In this case we define "transversal crest" a relief that joins a lingual cusp with a buccal one and "oblique crest" a relief in the upper molar that joins diagonally two cusps.

On the other hand, "negative features" are grooves, hollows and dimples:

- grooves: they are clearly visible in the occlusal surface of the posterior teeth; they divide the buccal cusps from the lingual ones (principle groove) or the mesial cusps from the distal ones (secondary grooves); indeed, other smaller grooves could be spread in the occlusal surface;
- hollows: always localized in molar teeth, they develop from the intersection between the principle groove and secondary grooves (central hollow) or between the principle groove and a marginal crest (marginal hollow);
- dimple: it is a depression on the buccal side of the molar at the end of a secondary groove.

Subsequently some information about the first molar (upper and lower) has been provided, because the molar teeth coming from Taddeo Cave and Poggio Cave belong to this dental typology.

1.2.2 FIRST LOWER MOLAR

The molars, whose shape looks like a parallelepiped, are used for grinding the food. The first molar usually has 5 cusps, which in relation to their size have a decreasing disposition as follows: Metaconide>Entoconide>Protoconide>Ipoconide>Ipoconulide. Sometimes auxiliary cusps are also recognized (entoconulide, etc...). Two slight furrows that start from the occlusal surface divide the buccal face into 3 lobes: a furrow which is positioned near the middle of the buccal face, while the other, shorter than the first one, is positioned towards the distal aspect of the buccal side. The lingual face is divided in two lobes by a unique furrow.

It is worthy to note that the first lower molar usually retains the primitive anthropoid five-cusped molar pattern known as the Y-5 arrangement, which gernerally is typical of the dryopithecids and of hominoids. Finally, this molar has 2 roots.

1.2.3 FIRST UPPER MOLAR

Like all the molars, we can recognize a trapezoidal shape with the major base in the occlusal face and the minor base in correspondence of the cement/enamel junction. Four cusps are often present, of which the decrease dimensional order is as follows: Protocono>Paracono>Metacono>Ipocono. The buccal face is divided in two similar lobes by a longitudinal furrow, while in the lingual face the two lobes differ in size. Indeed, the mesial face is taller and larger than the distal one.

Unlike the first lower molar, the mesio-distal diameter (MD) is shorter than the bucco-lingual one. Three roots are present: two vestibular roots (mesio-distally flat) and one lingual (cone-shaped and bigger than the vestibular ones). A 5^{th} cusp, named Carabelli tubercle, may be present on the mesio-lingual face of the Protocono cusp.

1.2.4 CERVICAL LINE

The part of the tooth where the enamel of the crown borders with the cement of the root is called the cervical line (or cement/enamel junction). As we said before, even if we can cluster each tooth into a specific typology, there is a big inter and intra-population variability in tooth morphology and morphometry. Also the cervical line has a big variability but at the same time some regular trends in the same tooth typology can be recognized. Considering that the cervical line provides a very important role in this research because it is located in a part of the tooth less concerned by wear than the occlusal surface, a more detailed description is supplied.

In general, in the mesial and distal face of the tooth, the cervical line is convex toward the occlusal surface. This convexity is wider in the mesial side of the tooth than in the distal one. Furthermore, starting from the incisor to the molars, the convexity tends to decrease until it usually becomes almost flat in the third molar. In fact, while in the mesial face of the incisor, supposing the height of the cervical line could be 3,5 mm (and its distal face is one millimeter less), starting from the first premolar this height is considerably reduced.

On the base of these considerations about cervical line trend, two major groups can be described: the first one characterized by the anterior teeth and the second one by the posterior teeth. In the first cluster (anterior teeth), as said before, the cervical line is convex toward the edge of the crown in the mesial and distal face. Instead, this convexity is toward the apex of the root in buccal and lingual face. Sometimes these conditions are observed in first premolars as well. In premolars the buccal and lingual cervical line is usually regular, with a more or less emphasized convexity toward the root. More variable is the mesial side, even if within a range of 1 millimeter, while almost straight is the cervical line in the distal side.

In the molars the convexities of the cervical line are less emphasized, and often are not present. In any case some particular features can be observed. For the lower molars, an inflexion of the cervical line toward the root bifurcation is usually recognized in the buccal and lingual face of the tooth.

While in the first molar the mesial side of the cervical line could be irregular, in the second and the third molars it tends to be a straight line as in general in the distal side. Similar features could be observed in the upper molars, even if the buccal side seems to be often irregular, with a slight inflexion toward the root bifurcation. Typically the lingual face of the cervical line is more regular than the buccal one. In the lingual face a slight depression connecting the secondary groove between the protocone-ipocone and the apex of the root bifurcation, passing to the cervical line, can be observed. Along this depression a slight inflexion of the cervical line toward the root bifurcation could be recognized. For the mesial and distal side the conditions are the same of the lower molars.

CHAPTER 2

2.1 THE TRADITIONAL APPROACH IN THE STUDY OF THE SHAPE OF TEETH: MORPHOLOGICAL AND MORPHOMETRIC ANALYSIS

With the term “traditional”, coined specifically in the present research study, an approach to the morphological and morphometric study of teeth is presented that does not substantially differ from the analysis procedures utilized at the beginning of the XX century. If in fact a series of contributions over the course of the years that have favored a better definition of the morphological characteristics of teeth can be recognized, it is without doubt that already in the first scientific journals the morphological descriptions could boast a high degree of accuracy, even though there are, even in this research field, strong limits due to the subjectiveness with which the singular tooth features can be interpreted. Decidedly more anchored to the dawn of these studies is the morphometric analysis of teeth, that which should quantify the manifestations of the form, that in the best of cases remains limited to three simple measurements obtained by means of a caliper.

One realizes in this manner, within the same “traditional” approach, a strong lack of balance between a morphological analysis rather accurate in it’s general outlines (leaving out of consideration the subjectiveness factor that constitutes a large obstacle for researchers), and a morphometric analysis that absolutely is not able to take into account not only the singular manifestations that could be, for example, the cuspids, but even of the general dimensions of teeth. This discrepancy has brought some scholars to consider morphometric study a secondary component in the analysis of teeth with respect to morphological study, even though the usefulness of the dimensional contribution to evidentialize evolutionary tendencies is recognized: *“Measurements on teeth are comparatively less reliable than morphology for purposes of visualizing population differences or for tracing phylogenetic relationship. This does not discredit the usefulness of measurements as an evidence of evolutionary tendencies…”* (Sharma, 1985, 255).

It is not difficult to perceive behind this lack of balance technological motivations. Morphological description “simply” calls for a detailed observation of the tooth without the particular aid of mechanical or electronic instrumentation. The fundamental problem, that was resolved over the course of the ensuing years and that has furnished those contributions to which I alluded above, has dealt with the codification, the standardization of nomenclature through which to define those clearly noticeable forms: with a little bit of experience, the morphological description of the cusps, of the grooves, of the crests, etc., does not call for particular technical support and the indications furnished for example by ASUDAS (Arizona State University Dental Anthropology System) constitute a well articulated compendium currently utilized by the majority of researchers. The description of "non-metric" traits of teeth, in order to define variations found in modern populations, was developed in detail at the beginning of the last century (for example Hrdlička, 1920), descriptions successively supported by the introduction of reference system useful for bringing into line the work of various scholars (Dahlberg, 1956; Hanihara, 1961; Nichol et al., 1984). ASUDAS is a fundamental part of this movement that proposes to optimize the approach of the evaluation of the non-metric traits, fundamentally based on the recognition of a large number of significant morphological traits and on the modalities by which to record the degree of manifestation of these traits, in the prospect of reducing to a minimum the error committed by various observers and to furthermore facilitate the comparison of results from various scientific studies (Turner et al., 1991). Naturally, before and after the rigorous standardization realized by ASUDAD, the reference system were thoroughly used to define the expression of non-metric traits in the comparative study of hominid fossil remains (to cite only a few examples: Turner, 1985, 1990a,b,1992; Haeussler, 1995; Vargiu et al., 1997; Bailey, 2000; Guatelli-Steinberg et al., 2001; Irish and Guatelli-Steinberg, 2003).

The case for the morphometric study of teeth is different, where a measuring instrument is necessarily called for. Therefore the development of the morphometric approach is strongly conditioned by the development of measuring instruments, or by the contribution of innovative technologies born for different purposes but whose application can be extended into the anthropological field.

2.2 ODONTOMETRICS

The caliper constitutes the first instrument used for the measurement of teeth, and even now the large part of scientific publications in the anthropological sphere (regarding for example the determination of gender, of age upon death, the differences between human groups, etc.) and paleoanthropological repropose the limited measurements collected with this instrument: the mesio-distal diameter (MD), the bucco-lingual diameter (BL) and the height of the crown.

Just as the dimensions of a single bone from an individual can be used to study the sexual dimorphism within a population, the dimensions of teeth have been used for this same purpose, and many studies have been carried out in order to understand, in different populations, the distinguishing power of singular teeth. In general, the canine has demonstrated itself to be the tooth that returns the best results in discriminating the masculine component from the feminine (Kieser, 1990). The limits of these methods centered on the dimensional aspect of the sample are the same that are encountered utilizing the bones of the skeleton: in both cases, in fact, the dimensional variation of the sample studied presents itself as the same. But it is not just the continual variation that creates problems. What truly limits the use of the dimensional component for this type of estimation is due to the fact that there exist as many types of continual variability as there are partitions with which through the tassonomic approach we order the biodiversity on Earth. In certain aspects it is therefore a vicious circle. Differences permit us to classify organisms and it is therefore logical that when we attempt to carry out comparisons between class/genus, species, subspecies, and even different populations, it is necessary to take into account the intrinsic variability of taxa taken into consideration. Restricting the field to the current human species, in addition to the variability within each single population, there exists a continual variability even among the various populations. It is evident therefore that the results obtained for one population cannot be generalized for the others. This argument can then be extended to the different taxa. If I define in some way the variability of a species and I determine the principal components that this variability represents for me, it is not said that the same components are able to explain the variability of the other species that fall within the same genus.

All of these considerations are valid not only for the determination of genus on the basis of the dimensions of teeth, but also for the evaluation of the age of death in relation to the height of the crown (and therefore in reference to tooth-wear). In this last case an additional component of variability is added that contributes to impugn the trustworthiness of the result of the analyses: not only the Gaussian curve that represents graphically the variability in height of the crown of a tooth for each population and that is specific to that specific population, but in relation to different cultural and environmental factors (nutritional habits, illness, etc) dental-wear will manifest itself in different ways for each population, as among the singular individuals.

Regarding the differentiation of groups of humans on the basis of tooth dimensions there exists a problem of method. Utilizing only two/three measurements, as is generally done, to identify significant differences between human groups creates a strong uncertainty, considering in fact the difficulty often encountered in differentiating Modern Human from Neanderthal on the basis of the same measurements. The principal with which these measurements are utilized can be found in the same manner in paleoanthropology for the differentiation of various fossil types. Through this brief description relative to the use of tooth dimensions in various sectors of study, it has been possible to highlight the limiting aspects that in various conditions impugn the results of the singular studies, perhaps because for the most part it is not possible to generalize the results obtained on a population left out of a larger population of the same type, perhaps because there may come into play other variables that complicate the situation upon examination, perhaps because the values imposed only on 2 or 3 dimensions cannot reflect comprehensibly the variability of a population.

2.3 DIMENSIONS

On the whole therefore, the large part of scientific research that utilizes the dimensions of teeth are based on two-three fundamental measurements.

In the first place, it is necessary to clarify the definitions used in referring to these measurements. As Kieser (1990) states, the BL measurement has been indicated as thickness (Miyabara, 1916), diameter (Nelson, 1938), breadth (Schamschula et al., 1972) or length (van Reenen, 1966). Similarly, the MD measurement has been defined as width/breadth, with the respective terms "width" (Seipel, 1946) and "breadth" (Oliver, 1960), otherwise length of the tooth (Hrdlička, 1952; Hunter and Priest, 1960).

Goose (1963), after having pointed out the various terminologies proposed by various authors (length, width and breadth) suggests using "diameter" to indicate not only the MD measurement but also the BL one, because the other terms are customarily adopted to indicate the other parts of the body. In addition he also quotes a summary list relative to the different modalities with which the two diameters can be measured, a list which was later quoted also by Hillson (1986), that still now proposes the controversial terminology indicating that the MD diameter can also be defined as "length" (length), while the BL can be thought of as the breadth (breadth) of the crown. In any case, herein follows a summary description of the "confusing" situation that continues to exist in light of the different modalities which these measurements can be collected:

- Mesio-distal diameter (MD): in some works of the first half of the twentieth century the average length was employed, at times the greater one, the external or otherwise the length of the occlusal surface of the tooth, in every case following a plan suitable to the mesio-distal direction. In a revision carried out by Moorrees and Reed (1954), the mesio-distal diameter was defined as the greater mesio-distal dimension of the crown taken parallel to the occlusal surface, criteria usually followed in the study of fossilized hominid teeth, supported by Hillson (1986) and used by various other scholars (Potter et al., 1981; Lukacs, 1985; Kieser, 1985). In other studies (figure 1) it was defined as the distance between the points of contact with the neighboring teeth of the same dental arch, taken parallel to the occlusal plane: in fact Nelson (1938) points out that the MD diameter of the molar crown and premolars has to be measured parallel to the median mesio-distal axis of the crown itself in correspondence to the interproximal facets of contact, while the BL diameter has to be measured perpendicularly to this and at right angles with respect to the median vertical axis of the crown, a suggestion according to which even Brace (1979) afterwards orients himself. For the incisors and canines there does not exist a difference, while for the premolars and the molars the points of contact could not be in correspondence with the maximum mesial and distal extension of the crown, and therefore a choice to the detriment of the other can alter the final result. Other scholars, like for example Thoma (1985, p.86), advise to take as a point of reference the mesial face that often presents a flat facet on which a jaw of the caliper can be rested. The MD diameter is determined by closing the caliper, trying to remain on a plane parallel to the occlusal surface. In any case, Goose advises that one utilize the method based on the facets of interproximal contact (with the BL diameter perpendicular to this, without considering the position of the crown), because "…*the contact points are a natural anatomical feature*" (Goose, 1963, p. 127), a method later accepted by various scholars (Hinton et al., 1980; Jacobson, 1982). On the other hand, according to Tobias (1967), the MD size is the distance between two parallel lines, perpendicular to the mesio-distal axial plane of the tooth. He specifies, in addition, that this measurement must be taken according to a tangent passing respectively through the most external of the mesial and distal points of the crown, along a line parallel to the occlusal plane.

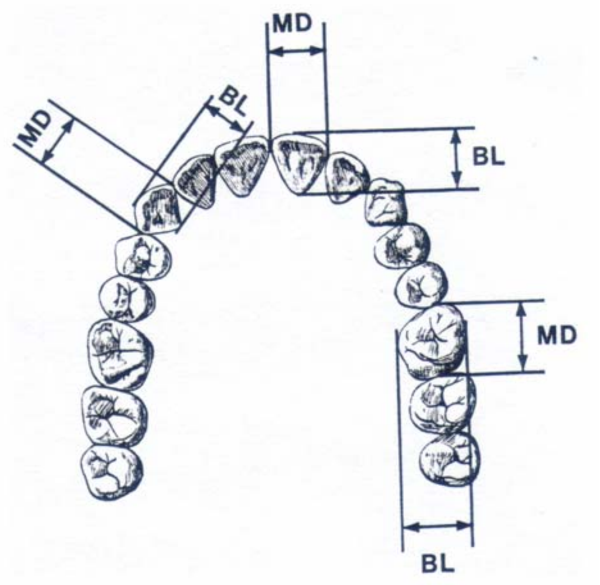


Figure 1. Bucco-lingual and mesio-distal measurements *(Brace, 1979).*

- Bucco-lingual diameter: usually the maximum diameter of the crown, taken perpendicular to the mesiodistal diameter (Goose, 1963; Hillson, 1986). While in anterior teeth this measurement is not so difficult, it is not the same for molar teeth. Two buccolingual diameters may be taken in molars. In lower molars these are respectively the diameters of the trigonid and the talonid. In upper molars these are across the paracone/protocone region of the crown and across the metacone/hypocone region. The only way to achieve a maximum measurement between their buccal and lingual crown sides is to rotate the crown so that the measurement is between the lingual bulge and the larger of the two buccal bulges (usually the most mesial), but in that case, the axis is no longer perpendicular to the mesio-distal diameter: *"(T)his measurments is subject to error because, for many of the molars, the most protruding portion of the facial aspect of the tooth will be toward the mesial and the corresponding point for the lingual will be toward the distal of the crown"* (Mayhall, 1992, 60-61). For this reason it is better to recognize explicitly that the condition of perpendicularity may need to be relaxed in order to achieve a simple maximum which provides a much more repeatable measurement definition (Tobias, 1967). Finally, Schamschula et al. (1972) suggest to measure before the bucco-lingual diameter and subsequently the mesio-distal diameter, taken perpendicular to the bucco-lingual one. A further difficulty is whether or not to include the cingulum bulge at the cervix of the tooth, which means that the size of the bucco-lingual diameter will be enlarged if it is included. It is part of the maximum crown dimension and so is normally included in bucco-lingual measurement (Hillson,1986).
- The crown height: this dimension is frequently invalidated by occlusal attrition. For this reason some investigators carry out these measurement to the deepest point between the cusps (Goose, 1963). Anyway, this measurement can be defined as follow:
    1. is measured from the occlusal surface to the cervical line on incisor, canines and premolars;
    2. in molars, by convention, crown height is defined as the distance between the tip of the mesio-buccal cusp to the cervical line, measured along a line parallel to the long axis of the tooth (Moorrees, 1957).

While the crown height is not so often employed because most archaeological and fossil assemblages of human remains show heavy attrition, the two diameters are usually measured in order to obtain specific anthropometric index:

- Crown module (CM) = (MD + BL)/2
- Crown index (CI)= (BL / MD)*100
- Robustness index (RI) = MD*BL

Crown module is the average diameter for each tooth. Crown index is the relative breath of the crown, expressed as a percentage. At 50, bucco-lingual diameter is equal to mesio-distal one. Above 50 bucco-lingual is the greater of the two. Below 50, mesio-distal is the greater. Robustness index is the area of the occlusal surface (assuming it to be rectangular).
Finally, some authors (Goose, 1963), have given mesio-distal and bucco-lingual diameter (Falk et Corruccini, 1982; Hillson, 2005), at the necks of teeth, measured parallel to the occlusal surface.

2.3.1 LIMITS OF THE TRADITIONAL METHOD

From what has been said it is evident that the traditional approach relative to the morphometric aspect of the study of teeth exhibits strong limits, clearly recognized by all scholars. These limits are listed as follows:

1. Teeth have irregular form and therefore no specific anatomical points from which measurements can be based exist on them. For this reason controversies can be generated concerning where to carry out the measurements. One can not be more explicit than Hillson when he states that: *"Teeth are complex, variable and rounded in form. They are not composed of flat surfaces and right angles. Reference points for measurements are difficult to define. Different observers may interpret these points slightly differently, so that care is needed when assessing results"* (Hillson, 1986, p. 232-233). Cruwys and Foley express themselves with different words but with the same view of the final result, according to which the variability that characterizes each single tooth involves the impossibility of completely understanding their shape: *"…there is a lack of easily defined datum points…Odontometrics is further complicated by the non-uniform shape of the tooth, and therefore any measurement will not be indicative of shape and vice*

versa" (Foley and Cruwys, 1986, p. 8,13). In addition, as Hillson et al. (2005) report, the rules furnished by various authors in order to determine the two diameters are unfeasible or at least they contribute to generating subjective errors. In the first place it is evident that changing the axis of the mesio-distal diameter, and therefore on the condition that one of the methods listed above is used, the bucco-lingual diameter perpendicular to it is consequently modified. In the second place, besides the fact that the possibility to monitor the orthogonality of the two measurements does not exist (and on this point we are directed to point 3), the maximum bucco-lingual diameter can not be perpendicular to the mesio-distal diameter or to the occlusal plane.

2. From what has been said in point 1 it is evident that two or three measurements, and the indexes that are recovered from them, cannot take into account the vast and complex morphometric variability of teeth.
3. It can also be understood how the reliability of these measurements can be affected by the inexperience of the researcher. In addition it is possible to incur subjective errors if the orthogonal and parallelism criteria described above are followed, because since there are not specific anatomic points in the dental crown the pretext of having adhered to a correct orthogonality essentiality depends on how the tooth was oriented at the moment of measurement. This is why it convenient to return to the maximum dimensions of the tooth, leaving aside the condition of orthogonality, following for example the instructions furnished by Tobias (1967). In a study, the error committed by one researcher or by multiple researchers at various times in measuring the same sample data of teeth was quantified, highlighting for example that the maximum mesio-distal diameter turns out to be subject to error in regards to the bucco-lingual diameter, in particular in molars and premolars and not in canines and incisors (Kieser and Groeneveld, 1991). More precisely, Kieser (1990) observes that there are various factors that interact in order to produce either an inaccurate or unreliable measurement of teeth (if it deals with dental molds, the manner in which they were obtained, the presence of cavities or tartar, the quality or the incorrect re-setting of the measuring instrument, etc.), among which are those accidental occurrences that are committed usually due to the impreciseness of the operator.
4. It is wrong to measure worn teeth: if the wear usually does not affect the BL diameter, almost always the length of the tooth, and therefore the MD diameter,

diminishes in response to the interproximal wear. Goose in fact (1963) distinguishes two types of wear: occlusal, that deals primarily with the height of the crown and in minor measure, in relation to the degree of wear, with the BL diameter, and the interproximal diameter, that deals instead with the MD diameter. Discounting for a moment the BL diameter, which is rarely invalidated by dental wear, the case for the MD diameter which deals in a different manner with the different dental typologies, is different, and certainly more intense in canines and incisors, and less evident but nonetheless present in premolars and molars. Is it therefore correct to proceed to the measurement of a tooth when an elevated level of wear is found and to compare the dimensions so obtained with those of a non-worn tooth? From this standpoint I find that, from an anthropometric point of view, a worn tooth should be considered on a level with a damaged bone where parts are missing and that therefore allows us to carry out only some measurements. Just as it is not possible to measure the length of a femur when half of the diaphysis is missing, it is not possible to ascertain what would have been for example the original height of a molar, since the occlusal wear acts first on the cuspids of the crown, just as the length (MD) of the crown of an incisor, drastically affected by both "incisive" wear and interproximal wear (in fact in incisors the maximum length is found in proximity to the third superior, or incisive, of the tooth). As Goose (1963) reports, some scholars have ignored dental wear, others have tried to face these problems by utilizing more or less arbitrary corrections or by defining age groups for singular teeth on the basis of wear. In any case wear remains a fundamentally important problem, and an objective limit in the morphometric study of teeth.

2.3.2 NEW DEVELOPMENT IN TRADITIONAL APPROACH

In the research of Hillson et al. (2005), the aim was to investigate alternative tooth measurements that would be less affected by occlusal and approximal tooth wear. Indeed, the purpose of the work was to examine the relationship of these new measurements with the usual crown diameters in unworn teeth, to test the reliability with which they could be measured and compare it with the usual crown diameters. These alternatives would allow a wider range of specimens to be included, e.g., in the study of dental reduction in Upper Palaeolithic and Mesolithic Homo sapiens. In addition, they would allow the little-worn teeth of children to be compared directly with well-worn teeth in adults. About the new measurements, one possibility for molars is to take diagonal crown diameters, from mesio-buccal to disto-lingual and from mesio-lingual to disto-buccal. This is a simple maximum dimension and the tooth is rotated to give the highest value, so personal judgment is not required when the measurement is taken. Another possibility is to take measurements at the base of the crown, along the cement-enamel junction of the cervix. The cervical diameters are not affected by wear until most of the crown has been lost, so they have a big advantage for archaeological purposes. This advantage is less important for bucco-lingual diameters, but is crucial for mesio-distal diameters, especially in anterior teeth. For this reason it was necessary to develop a new calliper for the cervical measurements: a 6-inch Mitutoyo Digimatic calliper was modified with 2-mm stainless steel rods (figure 2).

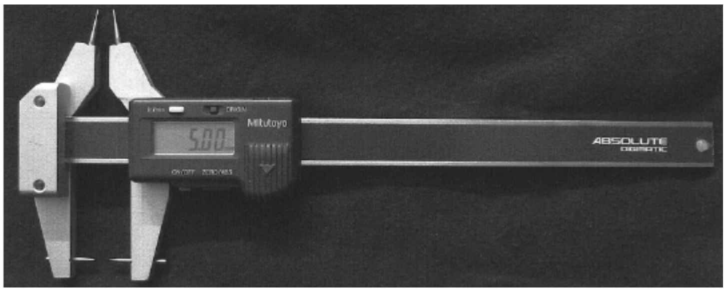


Figure 2. Caliper for cervical dental measurements developed in collaboration with Paleo-Tech, Inc. From Hillson et al, 2005.

The authors conclude that cervical and diagonal alternative measurements of the crown, can be performed as reliably as the more usual maximum crown diameters

2.4 NEW APPROACH FOR STUDYING TOOTH: TWO-DIMENSIONAL IMAGE ANALYSIS

Since 1970th some researcher have tried to overcome the limits due to the scanty information obtained with only two diameters. This development was achieved by means of image analysis of the occlusal surface of the crown (Biggerstaff, 1970; Hanihara et al., 1970), in the first time based on the measurement of the area inside the profile with a planimeter (LeBlanc and Black 1974; Williams, 1979). Subsequently, this new methodology was often used either for comparing the profile of the occlusal surface of different teeth or for comparing particular features of crowns: for example the projection surface of the cusps, the distances among their apexes and other two-dimensional measurements. Anyway, the fundamental principles of this method are always the same and are not changed along the years. In general these assumptions are as follow:

1. equipment: a camera or a digital camera is required;
2. tooth orientation: before image acquisition, each tooth has to be oriented. It is necessary to use the same orientation system for each dental typology; usually the

researchers try to rotate the tooth until the occlusal surface is orthogonal to the optical axis of the camera;

3. a reference metric system: a metric scale is positioned parallel and at the same level of the occlusal surface; by means of this metric scale calibration of each image could be prepared.

Even if the principle phases are always the same, in regard on the specific aim of a research same particular arrangement can be observed. In general, only isolated teeth have been considered, usually first and second molar (upper and lower, deciduous and permanent), and more recently same premolars.

Since 1990th two-dimensional analysis of the occlusal surface has became more frequent, certainly due to the huge quantity of information that is possible to use and because there is a decrease in subjective errors during tooth measurements.

Some researches were carried out to examine some morphometric variables, and the relations between them, in developing crowns of the maxillary first and secondary primary molar. The following morphometric variables were examined: perimeters and areas from the occlusal view; bucco-lingual and mesio-distal dimensions and intercusp distances; the angle between the line joining the disto-buccal, mesio-buccal and lingual cusps; and the height of the mesio-buccal cusp. An image-analysing technique comprising a photographic camera, a monitor, a computer with appropriate software (CUE 4; Galai Co., Migdal HaEmek, Israel) and a digital calliper with an accuracy of 0.01 mm (Beerendonk; Dentaurum Co., U.S.A.) was used (Peretz et al., 1997; Peretz et al., 1998a).

In another study the purpose was to measure the intercusp distances and angles of mandibular first molars in individuals with Down's syndrome, and in a control group, to compare the measurements of both groups, and to define the parameters that distinguish between the groups. A video camera, monitor, and a computer with an image analyser program (always the CUE 4, Galai Co., Migdal HaEmek, Israel) were used to measure all variables. The dental casts were put on a wooden plate and adjusted so that the cusps were on the same height, parallel to the plate and perpendicular to the camera. The cusp tips, reflected by the highest points, were then marked with a graphite pencil. The camera transferred the occlusal view of the teeth to the monitor on which the variables were measured with the image analyser program (Peretz et al., 1998b).

Harris e Dinh (2006), interested in the arrangement of cusp apices in the definitive tooth, used computer-assisted image analysis for measuring intercusp distances and angles on permanent maxillary M1 and M2 in a sample of 160 contemporary North American whites. A high-resolution digital photograph was taken of the occlusal view of each maxillary molar. The maxillary dental cast was positioned in a bed of fine metal shot, which permitted orienting the tooth's occlusal plane normal to the camera's central axis. One-millimeter grids were positioned on the buccal and lingual border of the tooth, so that scale was preserved. Cusp apices were marked beforehand with small pencil dots just large enough to be visible on the photographs. The occlusal view of a crown was standardized by visually minimizing the visibility of the crown's sides (buccal, lingual, mesial, and distal). In this case cusp heights were not used to orient the tooth. Distances (corrected to scale) and angles were measured using SigmaScan Pro 5.0 (SSPS, Inc., Chicago, IL).

In other studies the same variables, for example the distances between the cusps of the first lower molar, have been used for inter-population comparison (Sekikawa et al., 1988).

Ferrario et al. (1999) attempt to analyze and describe the intrinsic morphologic characteristics of the outline of the human molar occlusal surface and maximum circumference. Fourier analysis was used to quantify the shape of normal, healthy first permanent molars and to assess the effect of sex. A TV camera photographed each tooth, and an operator first traced and then digitized the outlines of the occlusal surface (marginal and cuspal ridges) and of the maximum circumference (equator) using an image analyzer (IBAS; Kontron, Munich, Germany). The system was calibrated on the focus plane of the occlusal surface before each acquisition, thus providing real metric data.

In a recent study, Kondo and Townsend (2006) have quantified overall crown size and cusp areas of a sample of human maxillary first molars, as well as expression of Carabelli cusps, by calculating areas from standardized occlusal photographs of dental casts. They aimed to calculate the areas of the four main molar cusps, and also Carabelli cusp, and to compare relative variability of cusp areas in relation to timing of development. Further objectives included making comparisons between males and females and describing how Carabelli cusp interacted with other molar cusps. Standardized photographs of the occlusal surfaces of maxillary first molars were obtained from dental casts using a Nikon CoolPix 950 digital camera. The molar crowns were oriented so that the plane produced by the cusp tips of the three major cusps was perpendicular to the optical axis of the camera. A metric scale was placed next to the tooth in the same horizontal plane as the occlusal surface. Measurements on photographs were performed with manual image measurement software (Visual Measure 32, Version 1.2, Rise Co.) on a personal computer.

At the same time, also in paleoanthropological researches two-dimensional approach have been used. In order to define morphological and morphometrical features of the first hominids, occlusal surface measurements of 196 Plio-Pleistocene hominid molars have been carried out by means of imagine analysis (Wood and Abbott, 1983).

In the study of Bailey (2004), the aim was to quantify shape differences observed in Neanderthal and anatomically modern maxillary molars and, in so doing, provide new information useful to developing standards for measuring variation in fossil hominins. High-resolution images of the occlusal surface of M1s were taken with a Nikon CoolPix 950 digital camera. The camera was mounted on a tripod and a levelling device was used to maintain a consistent camera angle. Each tooth was positioned so that the buccal and, where possible, distal cervical line were perpendicular to the camera's focal point and the tooth was in its approximate anatomical position. SigmaScan Pro 5.0 (SPSS, Inc.) imaging software was used to take linear, angular and area measurements from the occlusal photographs. Cusp angles were measured by connecting the apices of the four major cusps. SigmaScan Pro automatically calculated angles and distances between cusps. Individual cusp base areas were measured by tracing along the tooth perimeter and the major fissures separating the cusps.

With elliptic Fourier analysis, Bailey e Lynch (2005) have observed the differences between the P4 crowns of Neanderthal and Anatomical Modern Human to examine whether P4 occlusal crown shape is a useful tool for elucidating the taxonomy of an isolated P4 found in an archaeological context. Also Martinón-Torres et al. (2006) carried out an examination of morphological variation of lower P4 among various fossil hominin species with an emphasis on genus Homo. They used a Procrustes techniques (Rohlf and Slice, 1990; Bookstein, 1991; Robinson et al., 2002; Adams et al., 2004), starting from images of occlusal surface taken with a Nikon D1H camera fitted with an AF Micro-Nikon 105 mm, f/2.8D. The camera was attached to a Kaiser Copy Stand Kit RS-1 with grid baseboard, column, and adjustable camera arm. A levelling device was used to ensure that the lens was parallel to the baseboard and the cervical line. The magnification ratio was adjusted to 1:1, and a scale was included in each photograph and placed parallel to the occlusal plane. Their results indicate that external shape variation is closely related to the configuration of the occlusal morphological features and influenced by dental size.

Recently Peretz et al. (2006), using images of upper first molar (but also skull images) photographed with an Olympus Camedia C-3030 digital camera, carried out a study about the used of geometric morphometrics methods (a landmark-based approaches that use sets of two- or three-dimensional coordinates of biological landmarks). They argue that from a biological viewpoint, the use of landmarks may not be sufficient because they cannot describe some biological forms and patterns. For this reason sliding semi-landmark method was proposed, to capture and analyse outlines (Green, 1996; Bookstein, 1997). Peretz and al. compared two of the most widely used criteria to slide points along an outline: minimum bending energy (Bookstein, 1996, 1997; Green, 1996) and perpendicular projection or minimum Procrustes distance (Sheets et al. 2004). They point out that the minimum Procrustes distance is the best way to highlight biological inter-population relationship when morphometrical features are considered.

2.4.1 LIMITS OF THE 2D IMAGE ANALYSIS

We can separate the limits of the two-dimensional approach in three main groups: the first includes technical components, the second pertains methodological components and the latter concerns characteristic conditions of the tooth that can invalidate the 2D image analysis. A similar, but not identical, repartition has been suggested by Arnqvist and Martensson (1998), that define three groups for the mistakes made when you want to analyze landmarks in two-dimensional images from three-dimensional objects obtained through the techniques above-written. They suggest that the errors can be separated in "methodological errors" (e.g. the shaping of the sample in the case of a cast), "instrumental errors" (digital or optical distortion) and "individual errors" (subjective decisions), and they attribute to the latter the greatest part of the error, either for the subjectivity when the operator positions the point on the images, or for the subjectivity when the operator orientates the surface of the tooth before the image acquisition.

In the repartition below there are similar sources of error indicate by Arnqvist and Martensson (even if error made by using casts are not considered), but these errors are clustered in different ways as proposed by Baley et al. (2004).

In the first group there are: 1) type of picture (digital or photographic film); 2) parallax error of the camera; 3) software utilized for the measurement. Into the methodological group there are: 1) limits of the measurements; 2) lost of information; 3) orientation of the tooth; 4) setting the metric scale; 5) calibration of the scale and identification of useful points into the digital image. Finally, the third group includes: 1) the state of conservation of the tooth (in particular the wear) and 2) the obstacles to obtain teeth with paleoanthropological importance.

2.4.2 FIRST GROUP: TECHNICAL LIMITS

All the limits that concern the technical characteristics of the image acquisition are part of the first group. In particular:

- <u>Type of camera</u>: it is a relative limit, because generally the error is slight.

- Parallax error of the camera: the optical axis must be perpendicular to a reference plane. If the optical axis is not orthogonal to the reference plane, the images show a distortion that invalidates the next calibration and the measurements into the image.
- Software: there are several software helpful for the morphometric analysis, that include the calibration function of the image, the identification of the landmarks, with the possibility to trace the outline and to calculate area, perimeters and distances. The more a software appears sensitive to the definition of the details and allows higher precision in the points identification, the more the results will be reliable.

2.4.3 SECOND GROUP: METHODOLOGICAL LIMITS

- Limits in the measurements: two-dimensional method allows to obtain more morphometric information than traditional approach, but the measurements are only linear information (lenght, width, perimeter) and quadratic information (area), all of which are referred to a projection in a reference plane of the surface of the tooth.
- Lost of information: there is a remarkable lost of information during the image acquisition, although all the two-dimensional images will be taken from all the surfaces of the tooth (even if only the occlusal surface has been usually taken). The morphological features of a tooth (cusps, marginal crests, cingulum, etc..) are expanded in the space and so, for the correct morphometric evaluation of the individual characteristics and theirs links with the other parts of tooth, it would be necessary to use the whole virtual model of the tooth.
- Orientation of the tooth: it is a limit that penalizes the image analysis, not only the 2D, but also the 3D, because there are not standard practices for tooth orientation.
- Setting the metric scale: before taking a picture, in order to calibrate the image through suitable software it is necessary to set a reference metric scale in correspondence to the occlusal surface of the tooth (figure 3 and 4).

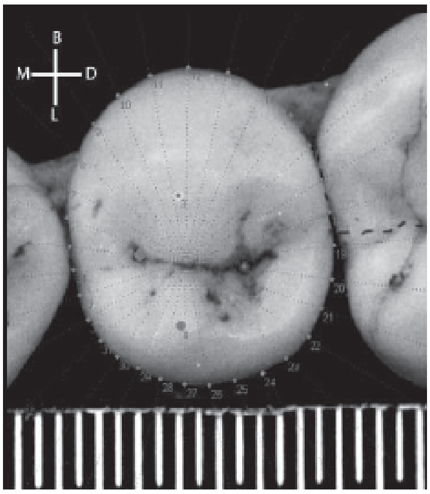


Fig. 3. Digital picture of an Anatomical Modern Human right lower P4: metric scale is shown below (Martinón-Torres et al., 2006, 525).

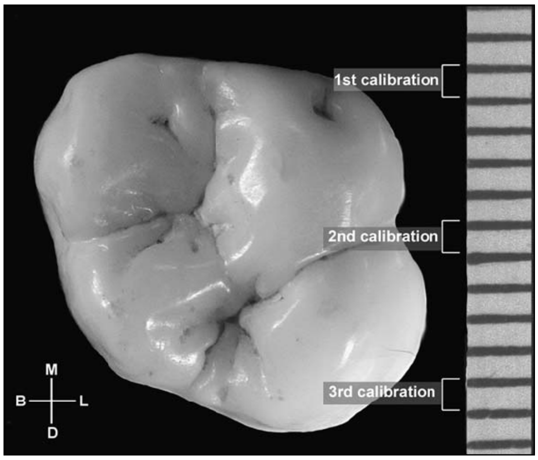


Fig. 4. Digital picture of an upper right M1: metric scale is provided on the side (Bailey, 2004, 188).

Setting the scale is a subjective choice and thus it is a source of error because it does not exist a reference point in the tooth for the identification of the suitable level. It is clear the inaccuracy of this system, because reducing the complex shape of the tooth to a flat surface it is a reductive approach. In several studies, the metric scale has usually placed in correspondence of the occlusal surface perpendicularly to the optical axis of the camera. How is it possible to define the occlusal surface of the tooth with a manual orientation? And so doing, is it correct to set a metric scale in relation to a indefinite occlusal surface? Some scientists utilize cameras that allow a scaled image acquisition, useful to obtain metric data without further calibration. (Ferrario et al.1999). However in most cases different approaches were used:

- *"…placing a rule in the plane of the tooth surface…"* (Robinson et al., 2002, 546);
- *"A millimeter scale, placed at the same horizontal plane as the buccal cusp apices, was included in each photograph for calibration"* (Bailey, 2004, 187);
- *"One-millimeter grids were positioned on the buccal and lingual border of the tooth, so that scale was preserved"* (Harris and Dinh, 2006, 516).
- *"…a millimeter scale was placed next to the tooth in the same horizontal plane as the occlusal surface"* (Kondo and Townsend, 2006, 197).
- *"…a scale was included in each photograph and placed parallel to, and at the same distance from the lens as, the occlusal plane"* (Martinón-Torres et al., 2006, 524).

- Calibration of the metric scale and identification of useful points into the image: the choice of the points in the metric scale and in the image is carried out manually, and so doing, it is possible to regard this error as subjective errors. Anyhow, with an accuracy control, repeating the measurement by the same operator or a partner, it allows to detect and to measure the error.

2.4.4 THIRD GROUP: INTRINSIC LIMITS OF THE TOOTH.

There are limits that are not due to the operator, because in many cases they depend on the condition of the tooth, even if these limits are closely connected with the instruments utilized.

- Wear: the analysis based on the occlusal surface are heavy invalidated by the degree of wear of the crown, which tends to reduce the height of the cusps until they are deleted.
- Accessibility to the fossil remains: it is an important limit, that generally invalidates the palaeontological studies, and particularly the paleoanthropological ones. It is well known that it is difficult to obtain prehistoric remains for carrying out scientific analysis. For this reason it is necessary to create a virtual database of three-dimensional fossil teeth, that must be accessible to all the scientists.

Most of these factors, that generally can invalidate the reproducibility of the measurements in two-dimensional image analysis, have been studied by Bailey et al. (2004), who has determined the error made by two scientists during the measurement of cusp base area in the same sample (upper M1 of Pan paniscus and Pan troglodytes). Since the results were not significantly different, the authors conclude that despite several techniques have been used to obtain the two-dimensional images and that slight differences in the orientation of the tooth have been used, the two-dimensional image analysis has not suffered for the errors commit by different scientists and so it can be used, even if they underline it needs to pay attention to the orientation of tooth and how setting the metric scale. The opinion of Robinson et al. (2002) is different, because the orientation affects the representation and the configuration of the points selected, especially for the occlusal surface. So the authors say that *"…further standardization for positioning these surfaces at the imaging stage might reduce this source of variation"* (p. 554), a thought that has stimulated the present research.

2.5 PLANNING AN INSTRUMENT

In a first time many attempts were carried out looking for resolving some of the limits said before. For this reason an instrument useful for supporting a tooth inside a Standardized Reference System has been planned. This instrument is comprehensive of a stand useful for fixing a digital camera, in such a way as to maintain the optical axis orthogonal to the

Reference Plane. A brief description and some figures about two prototypes never realized will be provided in order to show the different steps that have characterized this research: in fact, the impossibility to utilize worn teeth and the necessity to make a manual orientation of the tooth under investigation, leave a lot of problems unresolved.

2.5.1 FIRST INSTRUMENT

It is conceived for tooth measurements partially using the actual procedures that characterized the traditional odontometric approach. It is useful for tooth orientation and for acquiring digital images of the occlusal surface in a more objective way than the methods actually used in two-dimensional approach.

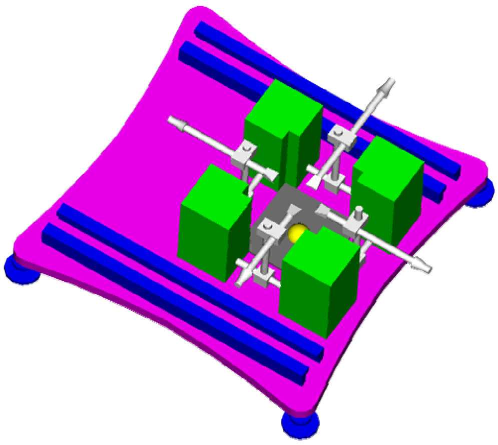


Fig. 5. First instrument

We can recognize 2 major parts: a base, where 4 approximately parallelepiped solids support as many sliding arms (figure 5), and a stand for supporting a digital camera. The 4 arms sustain the tooth and give the possibility to standardized an orientation system. For this reason the arms can be moved in the space (left/right, up/down and forward/behind direction), but without change their respectively orthogonal angles. The four solids have a fundamental role. The square drawn joining the internal corners of the four solids has well-know dimensions (figure 6). It is clear that each object positioned inside the square, at the same level, could be measured. So, a tooth may be fixed using the four arms, with the occlusal surface approximately at the same level of the hypothetical square. A digital camera mounted on a stand, with a fixed focus-lens and the optical axis orthogonal to the reference metric plane (the square), could be used to take pictures. Since all images had the same orientation criterion and reference system, we may use technical drawing software to create a grid of analogous dimensions of the square; each photo could be superposed on the grid and the profile of the tooth (or the cups, etc..) could be traced.

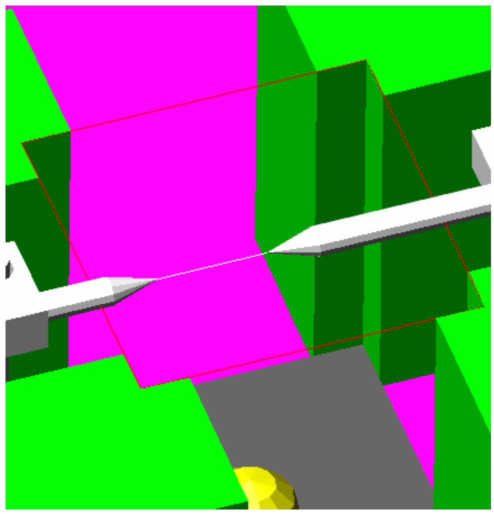


Fig. 6. First instrument: detail of the internal square drawn joining the internal corner of the parallelepipeds.

2.5.2 SECOND INTRUMENT

A second instrument has been planned starting from the same assumptions of the first one, but with some differences in the supporting tooth system.

The base has two lanes where a small carriage can be moved in left/right directions in relation to the arms (figure 7). Inside the carriage, specific guides give the possibility to another carriage to move forward/behind, always in relation to the arms. This last carriage has a vice for the fixation of the tooth, and it is able to tilt the tooth in anterior-posterior and laterally direction.

By means of the carriage it is possible to bring the tooth near the arms, and with the contribution of the mobile vice and the arms themselves, starting the orientation of the tooth (figure 8). Removing the arms concerning the buccal/lingual direction, a photo could be done using the same procedures said before. In this case, the metric reference system is defined by the two arms relative to the mesial/distal direction, which distance could be measured.

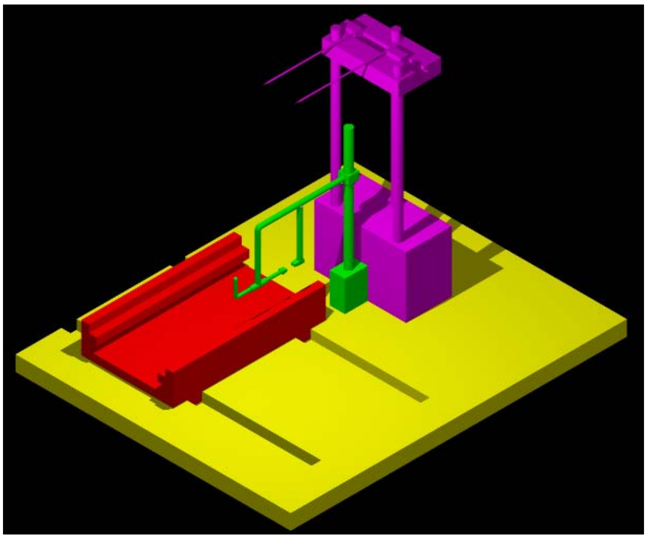


Fig. 7. Second instrument

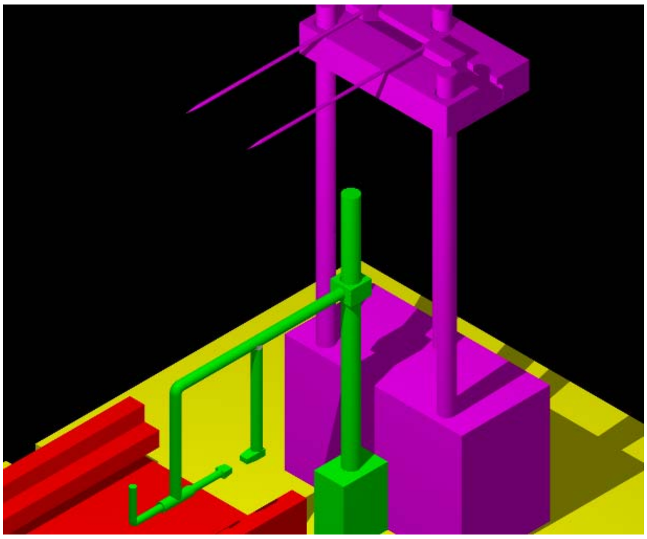


Fig. 8. Second instrument: detail of the arms

Anyway, even this instrument doesn't allow us to resolve all the problems. The instrument is more sophisticated, but the orientation system remains a manual procedure, hence it depends on the chooses of the researcher. Indeed, considering that it is an expensive instrument and it might only be used for two-dimensional image analysis (missing a lot of tooth information about the crown and the root), it is necessary to develop a different approach that is released from the traditional approach.

CHAPTER 3

3.1 NEW TECHNOLOGIES: THE THREE-DIMENSIONAL IMAGINE ANALYSIS

Over the last few years there has been a considerable development of the instruments aimed at the acquisition and virtual restoration of the three-dimensional models of any kind of object. Also the paleoanthropological studies use technologies, which are mainly conceived for medical and industrial purposes, but whose usefulness has proved unquestionable since the first anthropological works. In particular, I refer to the CAT (computerized axial tomography), which is born in 1972 (Hounsfield, 1973), and in the eighties, besides being employed in the medical field, made the study of several Egyptian mummies possible, thus making it possible to virtually restore the 3-D geometrical model of the body hidden by the linen bandages.

The CAT, then the CT (computer tomography), are more and more employed in the paleoanthropological field to scan fossil finds of exceptional evolution interest, and recently the micro-tomography turned out very useful to study quite small finds, like teeth (Lee et al., 2006; Peru et al., 2006; Yu et al., 2006;)

There are different scanning systems, most of which allow to detect the outer surface of the object, unlike the CT, whose slides record even the inner section, thus allowing to extend the analysis to those parts of the subject otherwise inaccessible without an invasive approach. What comes out is that it is possible to choose the suitable scanning instrument according to the research purpose: if the 3-D restored model has to supply data regarding the inner aspect of the original find, the CT is necessary; instead, if it is enough to have a 3-D model reproducing the outer morphology of the object, volumetrical but “empty” inside, several scanning systems are available, like for example mechanical and piezoelectric digitizers, laser scanner, confocal microscope.

It is interesting to notice that these new technological resources, supporting paleoanthropology and anthropology, have not been used in an indiscriminate way, but they almost always concerned specific kind of finds, even if some scholars lately extended the application field to other situations, which were kept more aside the research world so far. In particular, as mentioned above, the fossil finds in the paleoanthropological field are more and more scanned through the CT, with a particular partiality for the cranial finds, whose virtual data bank is becoming larger. This difference in favour of some skeletal fossil finds has to be logically related to a higher possibility of the former to return useful information for the phylogenetic reconstruction, as well as to answer other questions, which are really interesting.

As a matter of fact, the tomography of a skull allows to obtain a 3-D geometric model, whose endocranium can be analysed and the encephalon virtually reconstructed. This can open up wide researches dealing with the hominids inclination towards the objects manipulation, with the origin of language, the development of theories relevant to the socialization and learning ability, which lead to theories on the origin of culture , etc. Besides, the skull morphology is in itself a source of significant information for phylogenetic studies.

If in paleoanthropological field the fossil skulls are more and more often scanned through the CT, and in the anthropological or archaeoanthropological field mummies hold supremacy among the remains usually scanned, in both fields we see a large-scale use of the scanning systems aimed at the teeth study, right for the big information potential they have. This is due to a considerable genetic element as well as the propension, more or less indirect, to record a series of processes characterizing the life of the individual.

Except these finds, there are few virtual restorations of post-cranial bony pieces, even if the possibilities offered by these new technologies create a field of the anthropological research, which is really promising, first of all the increase in the objectivity of the skeleton remains studies reducing the choice range for the operator.

3.2 THE SCANNING INSTRUMENTS IN THE TEETH STUDY

In the previous pages we referred to the importance of teeth in the anthropological-paleoanthropological field, then to the information, which can be obtained from them in order to assume phylogenetic reconstructions, outline population dynamics, perform paleopathological studies, etc. These are research areas regarding our past, which contribute to the study of human in a diachronic perspective. However, it is evident that the main interest aiming at the comprehension of the dental morphology-morphometry, as well as of their spacial arrangement in the alveolar arch and at the comprehension of the dental and paradental pathology (tumour diagnosis, wounds due to a trauma, as well as articular maxillary and mandibular problems), is in the odontological field, because the research results and the continuous development of the studies spread far and wide for the wellness and health of the living being.

So, once the potential of the scanning systems have been understood, thus the possibilities to investigate the teeth arrangement and their mutual relationship in the three space dimensions, with reference to the alveolar processes they are included in (passing the evident limits of the spacial analysis based on two-dimensional images), it comes out that the great part of the researches restoring the reconstrucitons of 3-D virtual teeth models are performed in the medical-dental field.

In paleoanthropological field and especially for studying teeth, new technology as 3D scanners and software for 3D restitution and virtual geometrical models analysis, only recently have been used. If on one hand the potentiality of these instruments are recognized, on the other hand three-dimensional approach is still expensive. Indeed, technical abilities are indispensable not only for scanning objects but also for merging the faces and for three-dimensional models analysis. For this reason first studies in this field growth as a collaboration between paleoanthropology and engineers.

One of the first studies in dental three-dimensional analysis was carried out by the Department of Anthropology and the Center for Advanced Spatial Technologies of the University of Arkansas (Zuccotti et al., 1998). Numerous studies have shown that tooth form can be used to predict aspects of diet and feeding behavior in living primates. Most such studies have thus far been limited to linear or area measurements. They describe a new method to characterize and allow the comparison of primate teeth in three dimensions using Geographic Resources Analysis Support System (GRASS) software. High-resolution replicas were taken of original unworn lower second molars of the extant hominoids Gorilla gorilla, Pan troglodytes, and Pongo pygmaeus, and the fossil Miocene catarrhines Afropithecus turkanesis and Dryopithecus laietanus. Casts were poured with an epoxy resin and catalyst (Tap Plastics, Inc., Dublin, CA). Data were collected using a Polhemus 3Draw Pro (Polhemus Inc., Colchester, VT) electromagnetic digitizer. This consists of a tablet and stylus that allow the user to trace the occlusal surface of a specimen, recording x, y, and z coordinates. Specimens were placed at the center of the tablet for consistency, with the buccal side facing the x axis. Approximately 400 coordinates were collected for each surface at a rate of 70 points per minute to a resolution of 0.13 mm. The digitizer was attached to a PC microcomputer, and coordinates of each point were stored as ASCII files using the 3Draw software (Polhemus Inc., Colchester, VT). The resulting ASCII files were imported into GRASS 4.1, which can be used to interpolate an occlusal surface, and to gather data on volume, slope, and aspect of individual cusps (figure 1). Further, they show how GRASS tools can be used to generate the volume of liquid that

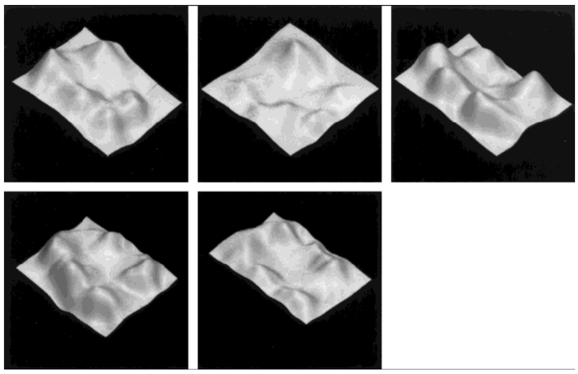


Fig. 1. Surface models of teeth examined in this study (upper left to lower right): Afropithecus, Dryopithecus, Gorilla, Pan, Pongo. From Zuccotti et al., 1998.

would accumulate in each tooth's basin (a measure of basin area), and the directions and intensity of drainage over the occlusal surface. Considering limitations to the resolution of the digitizer and the geometry of the stylus used in this study, thin-plate splining was necessary to create a model of each surface. For this reason at the end of the article, they emphasized that a device capable of collecting points with greater precision, such as a high-resolution laser digitizer would eliminate the need for interpolation.

The advent of computers has allowed the use of new analytical methods to record and analyze tooth crown morphology of small teeth with almost no loss of shape information. Jernvall e Selänne (1999) present a laser confocal microscopy technique to generate digital elevation models (DEMs) of mammalian tooth crowns. As mentioned above, digital elevation models can be transferred to Geographic Information System (GIS) software as well as explore tooth shape parameters by surface rendering computer programs (Reed 1997; Zuccotti et al. 1998). They used a Zeiss Axiovert 135M microscope with the BioRad MRC-1024 confocal system and an American Laser Corporation 60WL argon/krypton laser (maximum output 100mW) located at the Institute of Biotechnology, University of Helsinki. The confocal scanning is operated via Lasersharp software package (BioRad). Teeth or casts were attached with Blue-tack onto an objective slide and oriented by eye to a desired plane. In general, they arranged the teeth so that the tips of the main cusps fell on the same horizontal plane. A tooth is optically sectioned with 25-100µm intervals using a laser confocal microscope with fluorescence detection. The tooth is illuminated with a laser beam, and only light reflected from the focal plane is detected. The optical sectioning is done by moving the focal plane vertically. These confocal microscopes have a motorized focus that allows accurate changes in the focal plane and automated collection of optical sections (figure 2).

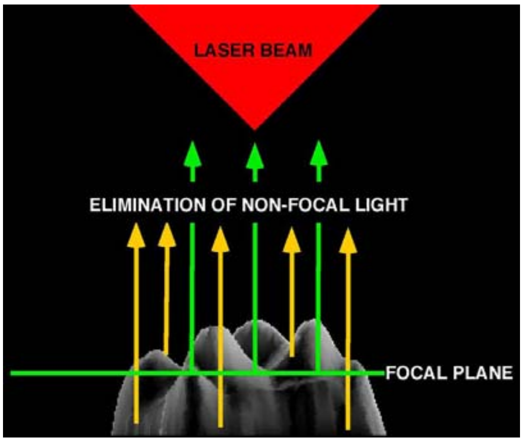


Fig. 2. A tooth is optically sectioned with a laser confocal microscope. The tooth is illuminated with a laser beam, and only light reflected from the focal plane is detected (green). The optical sectioning is done by moving the focal plane vertically. From Jernvall e Selänne, 1999.

They used the 3Dview version (public domain by Iain Huxley) of National Institute of Health (NIH) Image software to make high-resolution digital elevation models (DEMs) from the image stacks, considering them analogous to geographical data. This enables the use of GIS software that often have powerful image analysis capabilities. Jernvall and Selänne (1999) then demonstrated that various new measurements can be taken. For example, they used the areas of longitudinal and transverse slopes to determine cusp elongation to identify subtle differences in selenodonty in hedgehogs.

Also Ungar e Williamson (2000) recognize the potentiality of GIS for tooth analysis. They described the potential of dental topographic analysis to document and analyze functionally relevant aspects of occlusal morphology in variably worn teeth of G. gorilla. They reconstructed a wear sequence for lower second molars of gorillas using variably worn teeth by scaling and aligning these teeth in an identical manner. Wear sequence models may be compared among taxa and analyzed for their relevance to tooth function. For this reason, three-dimensional point data representing the occlusal surface of each tooth were collected. Data points for individual teeth were then aligned and scaled and imported into the GRASS 4.1 (U.S. Army Construction Engineering Laboratory) GIS package as a digital elevation model (DEM). It is worthwhile to notice the different scansion system they used for DEM reconstruction. Reed (1997) suggested using a reflex microscope (Reflex Measurement Ltd.) to collect coordinate data for teeth, but it is an extremely tedious and time-consuming endeavor when hundreds if not hundreds of thousands of points are needed to adequately characterize a tooth's surface. As mentioned above, Zuccotti et al. (1998) suggested that a 3Draw Pro (Polhemus Corp.) electromagnetic digitizer might be used to collect such data, but this procedure is impractical for smaller mammalian teeth because the resolution of this digitizer is only 0.13 mm. Finally, Jernvall and Selänne (1999) suggested the use of a confocal microscope, very effective for digitizing small teeth, but it restricts tooth sizes to less than 10 mm in diameter, somewhat smaller than many mammal teeth. Instead, Ungar e Williamson (2000) collected point data using a modified Surveyor 500 laser scanner with an RPS 450 laser (Laser Design, Inc.). The scanner has a maximum resolution of 0,0254 mm in x, y, and z dimensions and a maximum work envelope of 152,4 mm × 152,4 mm × 304,8 mm. In this study, they created a DEM from points sampled at an interval of 0,0508 mm. In the opinion of Ungar e Williamson (2000), the laser scanner presents a good compromise between work envelope and resolution because it is capable of collecting data for all but the smallest mammal teeth.

Other researches move in the same direction, mainly addressed to characterize and compare tooth form in variably worn teeth. In fact Ungar et Kirera (2003)[1] outline a procedure to characterize and compare functional aspects of primate occlusal morphology for worn molar teeth using a laser scanner to generate 3D points from the surface of a molar tooth, and geographic information systems software (ARCVIEW 3.1 with the Spatial Analyst extension,

[1] See also Kirera et Ungar (2003).

ESRI, Redlands, CA) to model and measure functional aspects of occlusal morphology. This study examined lower second molar teeth of wild-caught Gorilla gorilla gorilla and Pan troglodytes troglodytes specimens from the Cleveland Museum of Natural History. Occlusal surfaces of these replicas were scanned with a modified Surveyor 500 scanner using an RPS-150 laser (Laser Design, Minneapolis). The authors remark the importance to include worn teeth in studies of primate dental functional morphology, because most fossil species are represented by few if any unworn teeth and the study of how tooth wear affects form will provide new and important insights into how natural selection acts to maintain efficiency for fracturing foods with specific material properties despite loss of dental tissue with age.

It is clear the validity of the laser scansion approach for three-dimensional virtual reconstruction of the occlusal surface of the teeth and the follow analysis by means of GIS software. This is true not only for understanding ecology and behavior adaptation of extant apes (Dennis et al., 2004), but also for fossil hominids (Ungar, 2004). Indeed, new opportunity are provided by CT for whole 3D reconstruction of dental fossil remains (Alt and Buitrago-Téllez, 2004).

3.3 THREE-DIMENSIONAL APPROACH FOR TAXONOMIC PURPOSES

If it is clear that new technologies provide great potentiality in dental researches, it is also evident the lack of standardized methodology in order to use the whole three-dimensional geometric model of the tooth. As mentioned above, almost all the researches are based on diet or ecology and behavior reconstruction, and in general only the occlusal surface is observed. In this way a lot of morphological and morphometrical tooth information (the whole crown or the root) are not evaluated, and taxonomic analysis for philogenetic aims are unsupplied.

For this reason it is necessary to develop a standardized approach based on three-dimensional virtual models of the teeth that permits a more detailed investigation of the tooth useful for taxonomic purposes. This necessity has been considered in this research, where a new methodology for studying first molars teeth has been standardized: as you are going to see in the second part of the thesis, this approach is more objective and permits to use more data than traditional approach or other recent works based on two-dimensional and three-dimensional approach.

SECOND PART

INTRODUCTION TO THE METHODOLOGICAL SECTION

In the next pages a new methodology for tooth morphological and morfometrical analysis will be discussed. Some palaeoanthropological teeth have required a new methodology for fossil species classification, using a new approach that does not lose any of the tooth's morphological and morphometrical data. The molars of Taddeo Cave (upper right M1 and lower right M1) and the molar of Poggio Cave (upper left M1), of which a brief description will be furnished in chapter 5, were already examined some years ago, but in the case of the molars from Taddeo Cave the results were not useable. Professor Messeri of the Anthropological Institute of Florence described the specimens as modern type and he suggested that in the first phase of the Würm, Neanderthal and modern populations (anatomically modern humans) lived together in southern Italy. (Messeri, Palma di Cesnola, 1976). Subsequently a hypothesis about a Mediterranean Neanderthal population with typical features was proposed for explaining the particular morphological and morphometrical characteristics of the molars of Taddeo Cave (Mussi, 1992). However, identifying these teeth as Neanderthal depend more on the archaeological context of where the molars came from rather than their morphological and morphometrical features.

For this reason the molars of Taddeo Cave and the first upper molar of Poggio Cave (even if it is already considered be of modern human origin), have been scanned with a Roland Picza 3D digitizer, and three-dimensional geometrical models of the teeth were constructed. In order to increase the paleoanthropological sample, other Neanderthal teeth and Upper Paleolithic Modern Human teeth (casts) have been scanned as well.

These three-dimensional geometrical models can be compared only if they are positioned and oriented in a consistent reference system. This fundamental prerequisite is true not only in the 3D approach but also in the two-dimensional approach. Nevertheless there is not a standard method recognized for this procedure. Therefore samples of unworn first upper and lower molars of an anatomically modern human have been scanned. On the 3D virtual models we have compared newly conceived orientation system method in addition to those proposed in the scientific literature. The new proposed method, evaluated to be the most efficient one, is based on the choice of particular features which ensure an acceptable repeatability of the space positioning and orientation, independently from the particular shape and wear under investigation.

Following that, virtual geometrical models of the paleoanthropological teeth have been oriented with the new standardized methodology. By means of a CAD program, in all the oriented teeth (modern human and Neanderthal teeth) multiple sections of the crown were examined. For each section dimensional variables were calculated in order to make a statistical analysis.

The new methodology is made up of three parts:

1. the standardization of a first molar (lower and upper) orientation system;
2. the determination of methodologies for data collection (for example by means of multiple sections);
3. the elaboration of the data and the results.

CHAPTER 4

4.1 THE SITES OF POGGIO CAVE AND TADDEO CAVE

The fossil molars studied in this research come from two caves located in southern Italy (Poggio Cave and Taddeo Cave), in the province of Salerno. In this chapter some details will be furnished about the geological and archaeological context by which these teeth come from.

4.1.1 POGGIO CAVE

The Poggio Cave is situated in Campania, near Marina di Camerota (Salerno, Italy). Archaeological excavations were carried out at different times by A. Palma di Cesnola: between 1965 and 1967, in 1969 and finally in 1974. Layer 14, at the base of the geological stratigraphy, is made of crushed rock and blunt stones. Above this, there are layers of a yellow/brown earth-like matrix (from layer 13 to layer 3), also containing some lens of volcanic material (from layer 10 to layer 13 and layer 4). Layer 2 is defined by yellowish clay and silt, with scattered calcareous debris and stones of larger size. Finally, the last part of the stratigraphical series was destroyed by later chemical/physical erosions. The fauna of Poggio Cave was studied for the first time by G Bartolomei (1975) and then by B. Sala (1979a). They identified herbivorous and carnivorous animals: among the firsts were *Cervus elaphus, Capreolus, Capra ibex, Rupicapra, Bos primigenius, Equus caballus, Equus (Asinus) hydruntinus, Dicerorhinus sp., Palaeoloxodon sp., Oryctolagus cuniculus*, and among the seconds, *Ursus arctos, Panthera leo, Panthera pardus, Canis aureus, Canis lupus, Lynx lynx* e *Vulpes vulpes*. In regard to the considerations of Sala, based on the association between the animal species and their quantity variation along the stratigraphical series, three phases were recognized that are slightly different from the subdivision proposed by Bartolomei (1975).

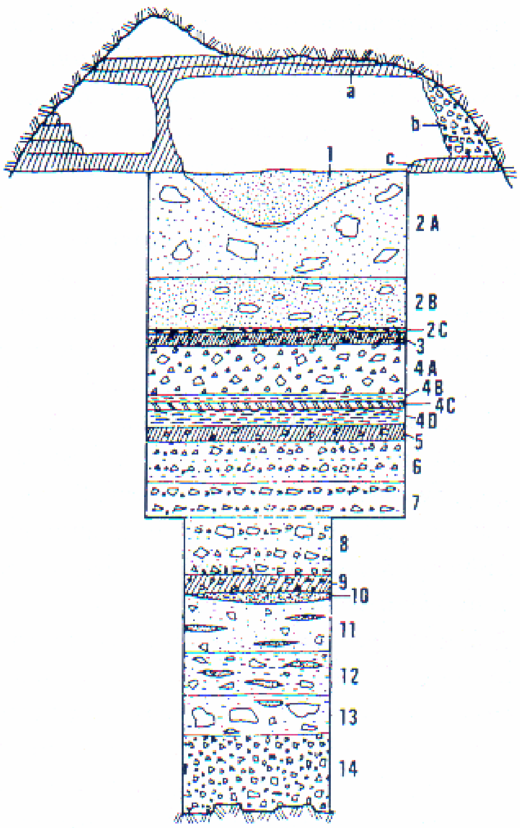


Fig. 1. Stratigraphic sequence of the deposit of Poggio Cave (Marina di Camerota, Salerno). From Palma di Cesnola 2001.

The lower phase (made of all layers between 13 and 8), should depict the colder condition of the sequence, even if in this period the major woodland growth is shown. The middle phase (from layer 8 to layer 5), reflects less cold climate conditions but wetter than the first one, with an increase of open spaces. Finally, Sala believes that the last phase (layers 4-2) is similar to the first one. At the same time the results of his assumptions bring further changes to the chronological sequence of Poggio Cave. Whilst in a first time this stratigraphical sequence was associated to the Würm I, the results of Sala have lead in a different direction. Deer is the most typical animal in the Fauna of Poggio Cave. After that there are goats and rare skeleton remains of rhinos, elephants, brown bears, lions, wolves, and foxes. This particular animal concentration is not a true imagine of the real würmian fauna in Italy or in South France. For this reason Palma di Cesnola ascribes all the fauna of the Poggio Cave to a rissian period. The lithic industry has been divided in three parts as well, but this subdivision is not the same that Sale used for the fauna assemblage because it is based on a different combination of the layers. Whilst in the most ancient lithic phase (13-11 layers) few artefacts have been discovered, the subsequent phase (layers 9-3) is characterized by a lot of scrapers from the Pre-musterian lithic industry: we can identify the simple scrapers, but also the double ones, the déjetés and the transversal scrapers. They are sometimes characterized by a progressive retouch, which is almost never intrusive, so this retouch does not look like the Quina type one. Other tools found are the Denticulates (they are very well supported by an abundance of evidence), and some modern instruments like burins, endscrapers, beaks and finally, besides these instruments, pointed tools with large bases. In general the tools are of small size and poor quality.

The Levallois technique is not present, but the lack of this technique is not proof of the archaic means of this Palaeolithic industry. Nevertheless, the antiquity of this industry is supported by some Quinson type tools, very few Tayac points, and some Clactonian notch. The scrapers (the major part Quina or "demiQuina" typology) found in layer 2 are also more frequent than denticulated tools, and with the exception of those the archaic artifacts we have seen before are

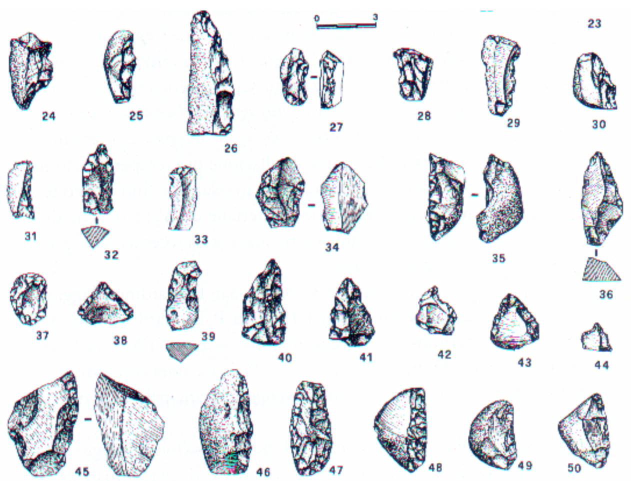


Fig. 2. Pre-Musterian of Poggio cave (Salerno, Italy). N. 24-44: from layers 13-3; n. 45-50: from layer 2. From Palma di Cesnola, 2001.

always present *(Palma di Cesnola, 2001).* In 1967 and 1974, during the archaeological excavation, some human remains were discovered *(Palma di Cesnola, 2001)*: a left upper first molar (from layer 6) and an astragalus (from layer 4). In regards to the chronological animal sequence elaborated by Sala's analysis, in which the sediment is associated to the rissian period, the first upper molar of the Poggio Cave (that it is included in the median phase defined by layers 8-5) should be ascribed to a phase of good climatic condition inside the Riss ice age. Unfortunately, it is not possible to provide more precise information.

4.1.2 TADDEO CAVE

In 1967, Alda Vigliardi, of the Prehistory and proto-history Italian Institute, obtained permission to carry out an archaeological excavation inside the Calanca Cave, whose entrance is located on La Calanca beach, along the Marina di Camerota coast (in the province of Salerno, Campania). Concerning this Cave, before the archaeological mission, Palma di Cesnola already commented on some various evidence relative to an Upper Palaeolithic industry. During this mission another cave was discovered above the first one, later named Taddeo Cave *(Vigliardi, 1969).* This cave has an elliptical plan, with a length of 16 m. and a maximum width of 10 m. narrows to 4 m. near the entrance. The height is not uniformly distributed, since near the entrance it varies from 1 to 1,4 m., while in the farthest point of the cave it varies between 0,3 to 0,6 m.

The stratigraphical sequence of the deposition is not complex. From the bottom to the top it is possible to distinguish a layer of concretion grey sand (some evidence from Tirrenian beach suggests that this is also the trampling surface during the use of the cave) [make sure that is correct], above which there is a thin red sandy layer that is covered by a huge stalagmite slab of variable thickness.

The fossil animal remains discovered in the red sandy layer were studied by Borzatti von Löwenstern, who recognized different kinds of big mammals: *Hippopotamus amphibius, Dicerorhinus mercki*, some remains of *Cervus elaphus, Capreolus capreolus, Sus scrofa*, some teeth of *Capra ibex* and, in less quantity, Borzatti recognized some remains of *Bos primigenius* and *Equus caballus.* Since these faunal remains are clearly relative to a wet-warm climate, the layer was dated to a middle phase of the Würm I. Subsequent analysis carried out by Sala confirmed the first assumption, dating the layer to an early phase of the Würm I. Hippopotamus remains indicate that a swampy place was close to Taddeo Cave, with woods and bushes, but horse and rhino remains also suggest a grassland environment not far from the Cave *(Vigliardi, 1969; Martini e al., 1976; Palma di Cesnola, 2001).*

In regards to the lithic tools found, the layer has provided very few artifacts: five scrapers, six retouched splinters, four denticulates and a notch. Almost all these artifacts are made on flat splinter usually slightly retouched, sometimes by means of the Levallois technique.

The artifacts show some characteristics usually found in the Typical Musterian facie, even though these few artifacts are not enough to confirm this assumption. On the basis of the fossil animal remains and the recovery of few artifacts, an occasional use of the cave has been hypothesised. However, in the same red sandy layer, 4 human teeth were discovered. These human teeth, first described by Messeri of the Anthropological Institute of Florence, have been defined as "modern type", raising the hypothesis that Neanderthal and modern populations had lived together in southern Italy *(Messeri, Palma di Cesnola, 1976).* Following information derived from the remains discovered in the Cave of the Fairies, were able to provide a new explanation which shows the existence of a Mediterranean Neanderthal population with typical features *(Mussi, 1992).* Their association with artifacts of the Musterian facie forces us to consider these teeth as Neanderthal in origin, because in Italy the Musterian culture is always related to the Neanderthal unlike the particular situation of the Near East where both Neanderthal and Homo s. used Musterian industry. For this reason, in the Near East the discrimination between Neanderthal and Homo s. in a site where only Musterian artifacts have been discovered, without any human bone remains, would be very problematic. Instead in Europe in general, and specifically in Italy, there is not any single case that could change the strong relationship between the Musterian facie - Homo neanderthalensis, and this is true for the more recent part of the Middle Palaeolithic as well.

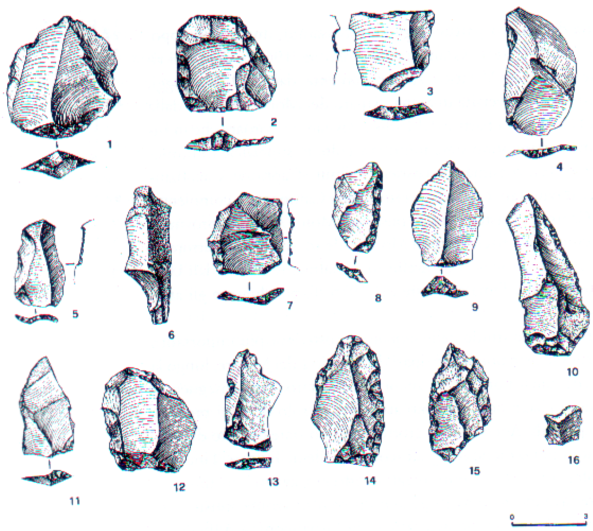


Fig. 3. Musterian of Taddeo Cave (Salerno, Italy). From Palma di Cesnola, 2001.

In any case the scientific approach of the palaeoanthropological analysis has to be free from these considerations; otherwise the results could be distorted by heavy biases.

CHAPTER 5

5.1 MORPHOLOGICAL DESCRIPTION OF THE UPPER M1 AT POGGIO CAVE (fig. 1)

It's the left upper M1 (figure 1), whose wear, according to the wear degree scheme of the maxillary teeth by Lovejoy (1985), would correspond to a D degree, compatible with the age of a 20-24 years-old individual: this, in the random hypothesis that the wear speed of human teeth during the middle-late or upper Pleistocene was the same as today. There is tartar, its trace (laboratory cleaning procedures partially erased it, so that only the mark of the 3rd occlusal is left), which starts from the cervical line, goes as far as 2 mm from the occlusal surface. Moreover, the root shows a relevant concentration of cement, probably due to the great stress borne by the tooth during life: it is not pathology, but a natural reaction of the organism at alveolar level, when it undergoes excessive loads.

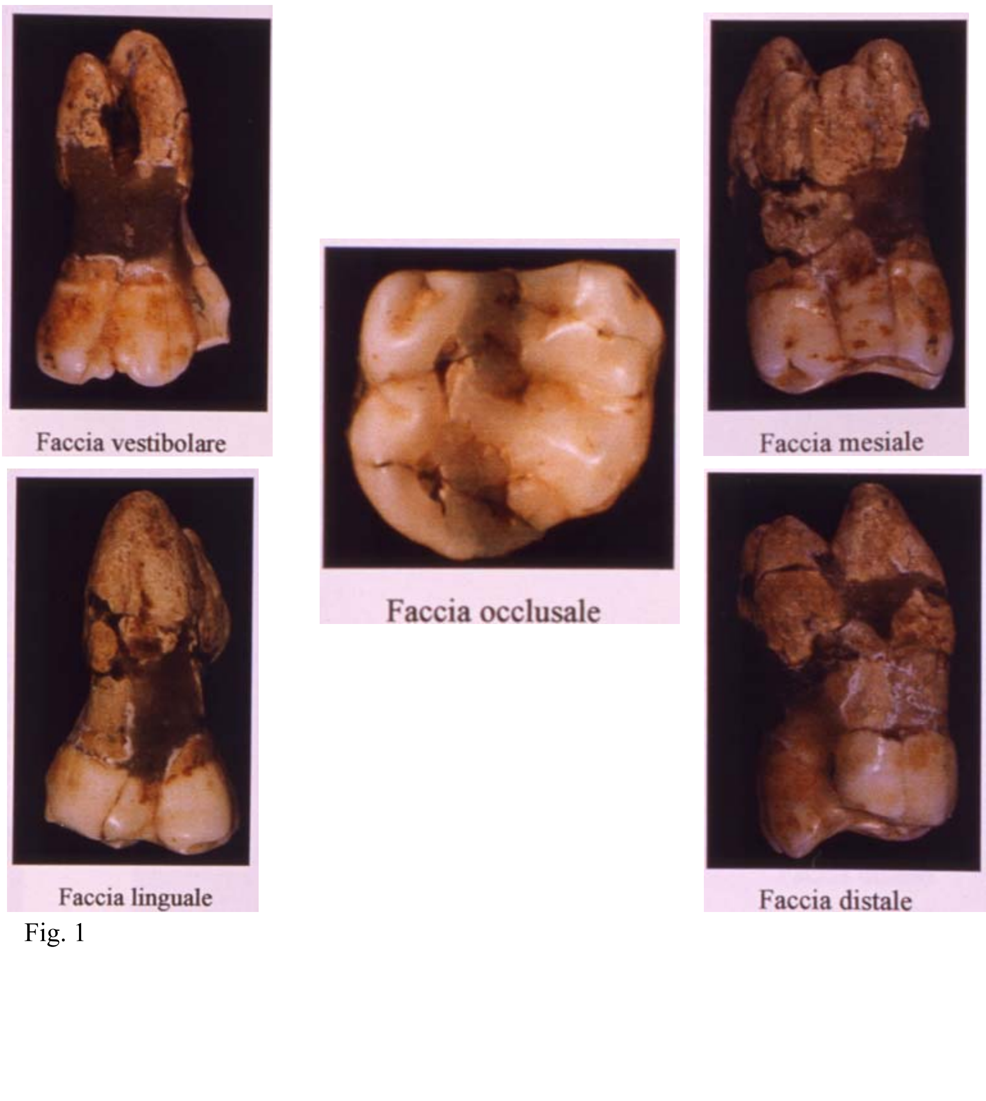


Fig. 1

5.1.1 BUCCAL FACE (figure 2)

The tooth observed in the buccal side shows a trapezoidal face, its longer base situated at the occlusal edge; it displays a rectilinear cervical line, interrupted by a radicular convexity with a tip towards the bifurcation of the root bifurcation. Laterally, the mesial and distal edges are convex, while the occlusal edge, displaying two arches created by the buccal cusps (paracone and metacone, the first larger than the second), makes a very asymmetric design in its intermediate tract, thanks to an accessory protuberance of the paracone which is bounded by the separating groove between the two buccal cusps. At the basis of the apex of the paracone and metacone there are some pits, visible only in the buccal side. The 3rd occlusal is divided into two lobes by a vertical groove: the buccal groove, which is the natural prolongation of one of the grooves of the occlusal surface. This face is convex in both longitudinal and transversal directions. On the mesio-buccal lobe, the transversal convexity passes through a vertical medium maximum, a sort of crest, laterally rimmed by two grooves of different length: in the image, the line ending near the paracone constitutes the distal groove of this crest. As a consequence, the mesio-buccal lobe comes divided into three secondary lobes, a main central one and two lateral, narrower ones. Behind the metacone one can see the distal projection of the hypocone, which is particularly marked. There are three radixes, two buccal ones and a more massive lingual one. As far as the buccal roots are concerned, most of the 3rd cervical and medial have gone lost, while the apical portions still remain, and tend to bend and to converge at their ends with their internal concave margin. In the image, an hatching indicates the wax reconstruction of the missing radicular parts.

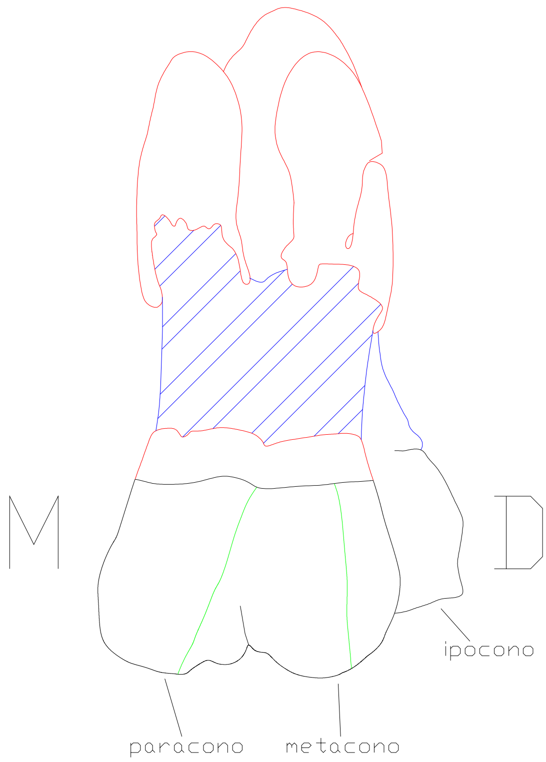


Fig. 2

5.1.2 LINGUAL FACE (figure 3)

It is bounded by an occlusal edge with radicular concaveness in proximity to the hollow, which divides the two lobes. Laterally, the mesial edge is convex, almost as high as the distal one, whose edge, instead, diverge from the cervical line with rectilinear gait; however, at the

3rd middle it generates a concavity which ends at the occlusal edge. The two lingual cusps are clearly visible: the distal (hypocone), decidedly wider than the mesial (protocone). One can notice, behind the cusp of the hypocone, the apex of the metacone cusp. When an upper molar is worn-out, wear is mainly visible in the lingual cusps, thus allowing the internal view of the buccal cusps in the lingual side. It is evident that this tooth was subjected to an average degree of wear. A hollow at the occlusal edge divides the two occlusal cusps in two lingual lobes of unequal width, and the distal is grooved by a slight crack. The root shows some gaps in its lingual prospect, but it is better represented than in the buccal face. So, it is more convenient to follow the distal contour starting from the cervical line, where it bends internally, producing a concavity, which changes direction already at the 3rd middle, creating the distal convexity of the only lingual root. Mesially, at

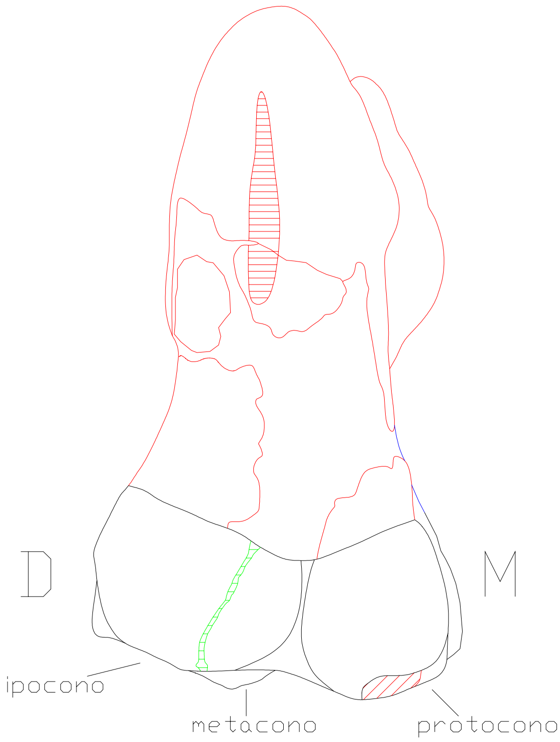


Fig. 3

the 3rd middle, a further concavity emphasizes the rounded feature displayed at the 3rd apical of the radix. This is centrally grooved by an evident hollow, which does not reach the apex, but whose gait towards the cervical line is interrupted by the absence of central portions of the root itself.

5.1.3 OCCLUSAL FACE (figure 4)

The face seems a trapeze rectangle, with lingual longer base. Among the human current upper M1s the most frequently found shape is the square one. The buccal edge is doubly convex for the presence of two lobes, separated by the vertical buccal groove. Other two lobes similarly shape the lingual edge (in its mesio-lingual edge there is no Carabelli tubercle), though their reciprocal dimensions are different with respect to the buccal ones. The mesial edge, perpendicular either to the lingual or the buccal one, is rectilinear, whereas the distal one is really convex. This face has four cusps; the two lingual ones are more worn-out than the buccal ones. The decreasing order of magnitude is the following:

HYPOCONE>PARACONE>METACONE>PROTOCONE

Usually, instead, in the current upper M1s the decreasing scheme is:

PROTOCONE>PARACONE>METACONE>HYPOCONE

It is noticeable that in the molar of Poggio Cave the order is practically inverted. A hypocone of small dimensions is typical of current molars, although this is a cusp exposed to wide variability, so that it can reach other cusps' dimension. However, such a big hypocone as that of Poggio Cave, becomes surely enough a discriminant factor avoiding its ascription to the Modern Human. Even among the Neanderthalians it is rare to find an M1 with such a big hypocone: for instance, in the Mousterian child of Châteauneuf 2, the decreasing order of magnitude of the cusps, which mirrors the general order of the cusps found on the second decidual molar, is as follows:

PARACONE>PROTOCONE>METACONE >HYPOCONE

This order is frequent among Neanderthalians, with some frequent variation in the position of the hypocone, which rises up until the second place: for instance, the first right upper grinder of Hortus VIII shows this scheme:

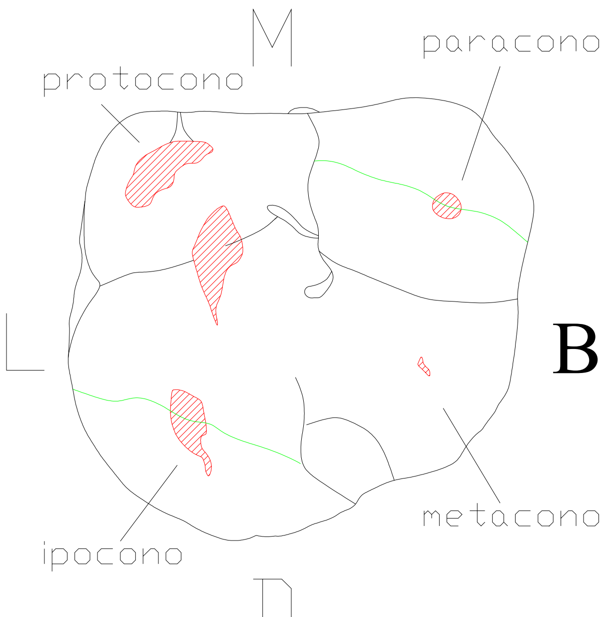


Fig. 4

PROTOCONE>PARACONE=HYPOCONE>METACONE

Or that of Hortus III (always upper right one), in which the protocone is missing, because broken, displays paracone>hypocone>metacone, thus a hypocone set neither in the last, nor the first position. On the occlusal surface one can observe a major mesio-distal groove, interrupted – near the centre of the crown – by an enamel bridge, or oblique crest, which unites the metacone to the base of the protocone, generating a sort of triangle whose vertex are the paracone, metacone and protocone. A further groove, a secondary or even a buccal-occlusal one, is that dividing the two buccal cusps, reconnecting to the main groove in proximity to the transversal crest of the paracone. On this cusp, as already told in the description of the buccal side, it is noticeable a small bulging of enamel bordering on the buccal groove near the edge. Another secondary or lingual groove divides the two lingual cusps, descending towards the main groove. Along its way a wear hollow interrupts it. It finally ends in another hollow, which originates in the mesio-distal groove.

5.1.4 MESIAL FACE (figure 5)

This face shows a rectangular shape, prolonging buccal-lingually. The cervical line is very wavy, with a huge central concavity towards the root, followed by a marked radicular convexity in the 3rd buccal. The buccal and lingual edges are slightly convex, the first longer than the latter. The occlusal edge forms a sort of "U" shape in the centre of the two cusps, which are visible on the mesial face, with wide-open arms, emphasizing the slight wear of the mesio-lingual cusp (protocone). However this one looks very rounded, if compared to the much more pointed buccal ones. A good portion of the root is available, where the bifurcation between the buccal-mesial root and lingual one is evident. This point is located quite near the apex of the two roots, higher than the buccal face.

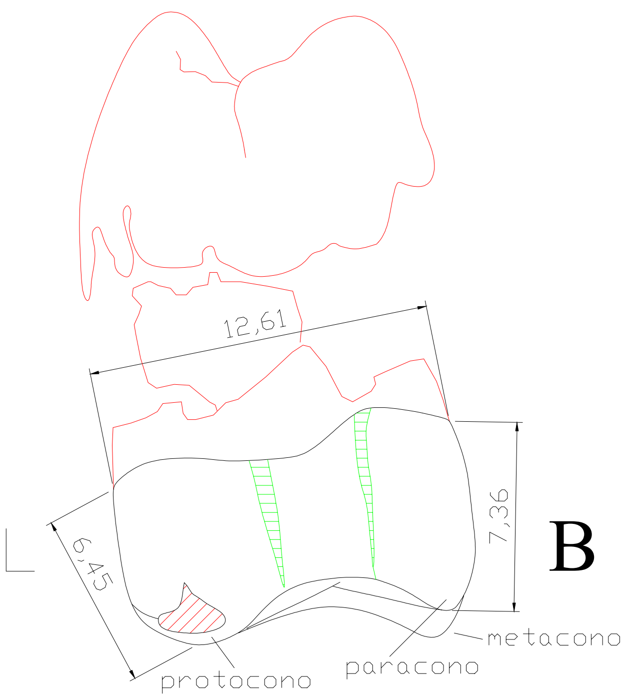


Fig. 5

5.1.5 DISTAL FACE (figure 6)

The face contour is trapezoidal, with a very scalloped cervical edge, and hard to interpret because of the fractures in the cervical line. The lateral, buccal and lingual edges are convex. Due to this convexity, the first edge, longer than the second, bends down towards the tongue. The free edge has a "V"-like, wide-open shape, because the lingual cusp is much lower than the buccal one. Evidently, the swelling produced by the hypocone, though not developing very much in height, leaves in sight the protocone behind. As far as the root is concerned, the situation is the same as on the opposite side, with a bifurcation point between the buccal-distal and the lingual roots situated in proximity to the apex.

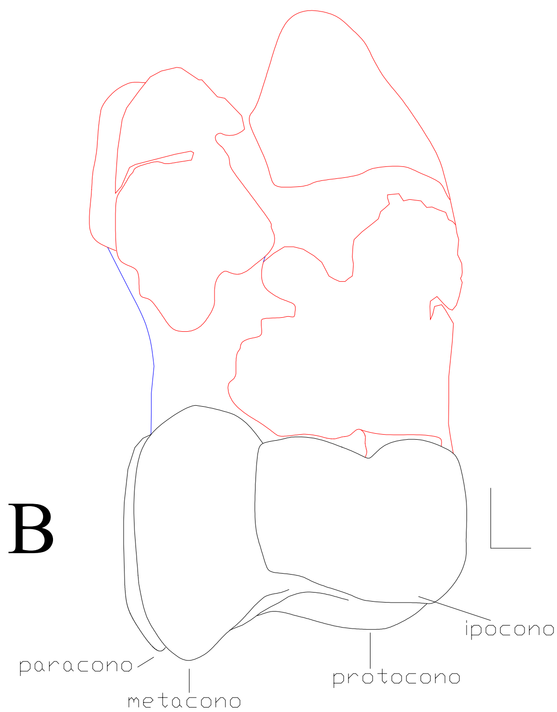


Fig. 6

5.2 MORPHOLOGICAL DESCRIPTION OF THE UPPER M1 AT TADDEO CAVE (fig. 7)

This tooth, both in shape and dimensions, evidently reminds the upper right of Hortus VIII (referred to Würm II), as the paracone and the hypocone are really voluminous. This same development of the cusps is clear in the Neanderthalian upper M1 at Krapina, the Quina, Spy the II, Petit Puymoyen, while the hypocone is much less voluminous in the current M1s (de Lumley-Woodyear, 1973). A feature, related to the crown in its whole, is a thin line of hypoplasia at 1,23 mm from the cervical line.

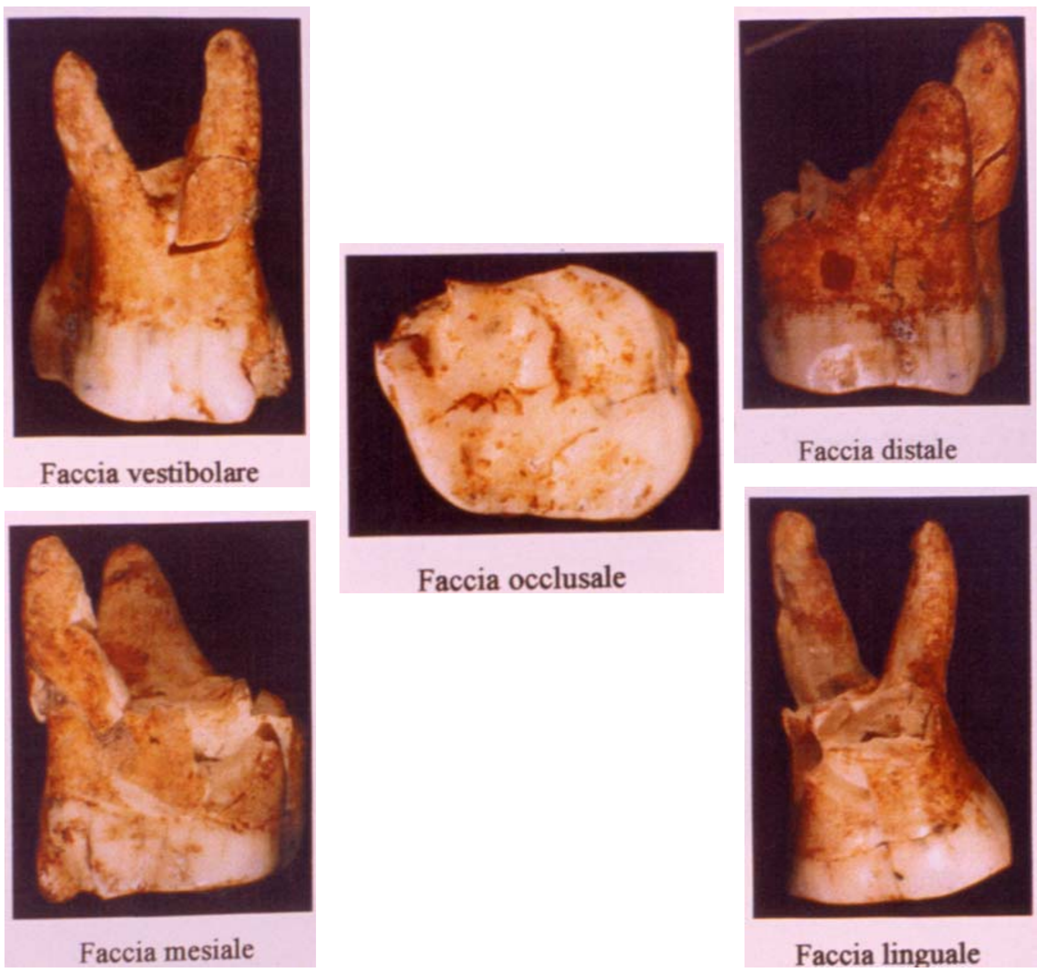


Fig. 7

5.2.1 BUCCAL FACE (figure 8)

The buccal face has a trapezoidal contour, with a larger occlusal base. The cervical line is slightly wavy (almost rectilinear), a convex distal edge, while a fracture in the mesial one impedes a precise identification of the lobe to which the paracone belongs. The same difficulties characterize the description of the contour of the free edge, which presumably would have been double-arched in correspondence to the buccal cusps. This face is convex either longitudinally or transversally. One can recognize the lobes, very easily distinguishable, divided by a buccal groove, which prolongs one of the grooves of the occlusal surface.

As in the current upper M1s, the roots are three, the buccal ones and a bigger lingual one. The two buccal roots are practically complete: they melt until half their length; they show a slight partition groove. They separate halfway of the 3rd middle with a noticeable divergence, then slightly converge in the 3rd apical. The buccal-mesial root (displaying a fracture in proximity to the bifurcation), has an MD diameter wider than the buccal-distal one, even if the latter has a more convex gait.

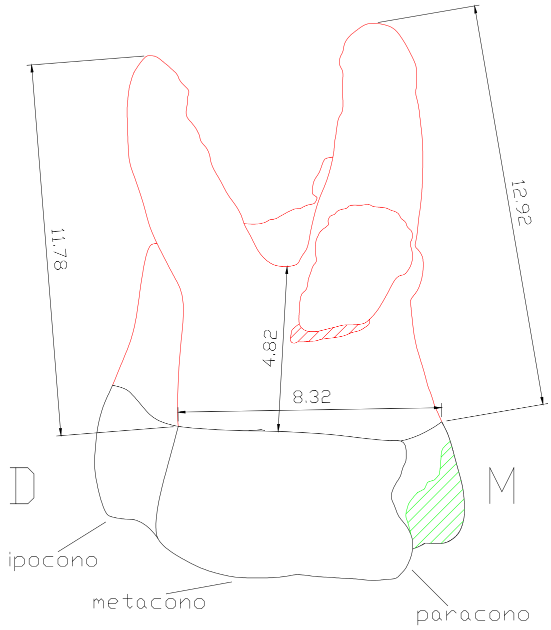


Fig. 8

5.2.2 LINGUAL FACE (figure 9)

The cervical part is particularly wavy, its concaveness in direction of the root. This double concavity is displayed again by the occlusal edge, really flattened by wear, in correspondence to the lingual cusps (protocone and hypocone). The distal edge is higher and more convex than the mesial one, and such a convexity is maintained in the 3rd cervical of the lingual root. This face is convex in vertical and transversal direction, and a slight vertical groove divides it in asymmetric lobes: the distal lobe is wider than the mesial one.

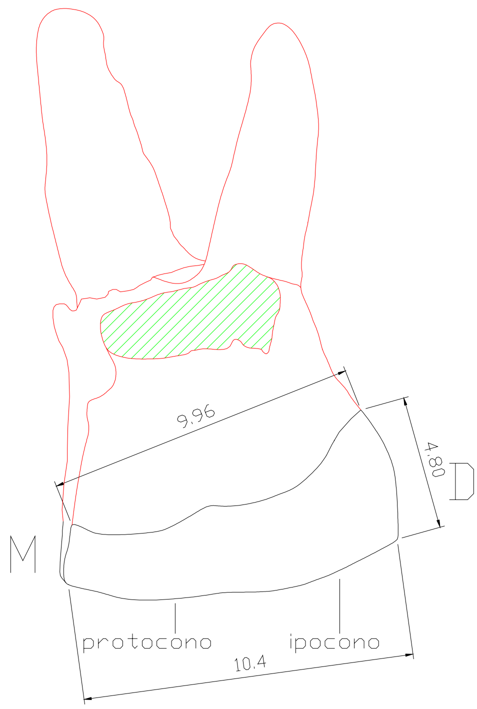


Fig. 9

The lingual root is fractured at the base of the separation point from the other roots, so that the section of its perimeter is visible.

5.2.3 OCCLUSAL FACE (figure 10)

This face is rhomboidal, with mesial edge slightly bigger than the distal part.

Four cusps, rather flattened by wear, are displayed in the following (decreasing) order:

protocone>hypocone=paracone>metacone

while the usual order one encounters in current M1s is:

protocone>paracone>metacone>hypocone

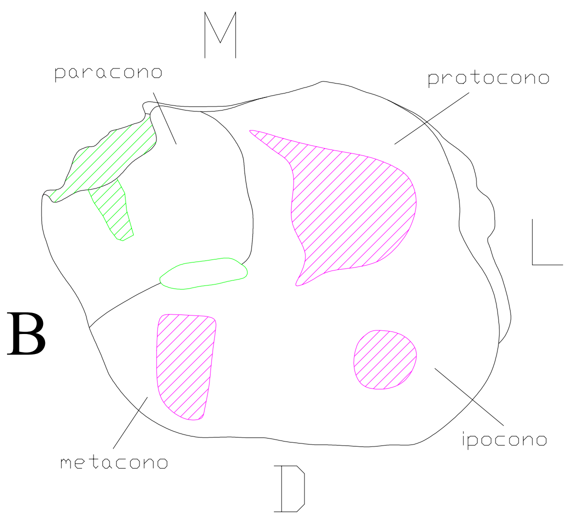


Fig. 10

The buccal crest is shaped as a double arch of a circle by the presence of the lobes, as well as the lingual crest, in which the scalloping is even marked. The mesial edge is subject to the swelling of the paracone and protocone, between which a concavity appears, whose real proportions are missing because of a lacking portion of the paracone. The distal edge is rectilinear, probably because of the big interproximate wear facet, which has cancelled its real conformation. Actually, in current M1s, the hypocone and metacone are the least wide cusps, so that the buccal edge, past the contour of the paracone lobe, roughly bends towards the distal edge, formed by the distal margins of the least wide cusps, facilitating the convex conformation. Even in fossil M1s the distal edge is convex, although the contour is wider, as the distal-lingual cusp is more expanded. The mesio-buccal hatching indicates the paracone fracture while hatching inside the occlusal surface is for the dentine arises by wear on the surface of the various cusps. The groove bounding the paracone is quite visible; a recess is present on its buccal-central. A slightly visible and highly worn-out oblique crest connects protocone and metacone.

5.2.4 MESIAL FACE (figure 11)

The cervical line is wavy, bending buccal-lingually, since the buccal side is longer than the lingual; however, both have a slightly convex contour, with a tendency towards verticalization. The occlusal edge is strongly flattened by wear - most lingually - so that the contour seems almost rectilinear, though in proximity to the paracone it deviates with a slight slope downwards. The face is prolongued buccal-lingually. Even the contact facet, situated along the free edge, has the same direction, though the front edge has been cancelled by the paracone fracture. The Carabelli tubercle is not visible. The lingual root is fractured (the hatching highlights the fissure), as well as the buccal-mesial, making it difficult to find its bifurcation point with the missing root. The buccal-distal root is visible at the back, less tapered than those previously seen in the buccal side, with triangular contour and noticeable base dimension.

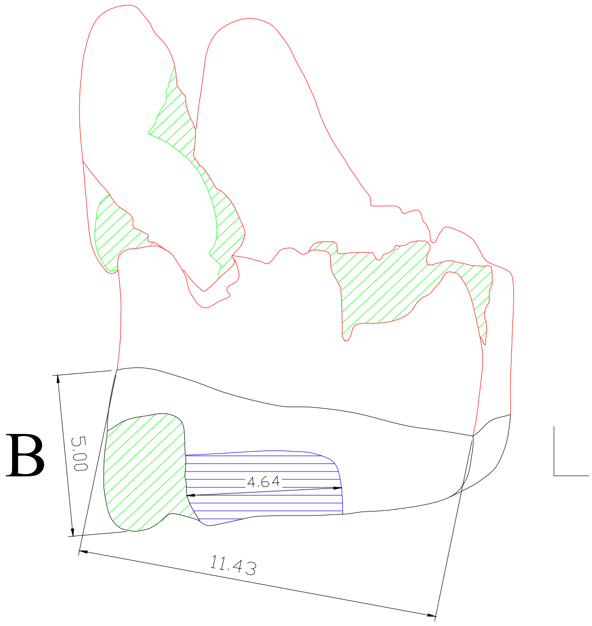


Fig. 11

5.2.5 DISTAL FACE (figure 12)

The cervical line is almost rectilinear, except for a coronal invagination in correspondence to the axis of the distal-buccal root. The buccal edge is more convex than the lingual, which is almost vertical and longer than the opposite lingual edge, visible in the mesial side. The occlusal edge is wavy, distal-lingually convex, but concave in the distal-buccal portion. This is due to the fact that the hypocone is less worn-out than the protocone (mesio-lingual cusp), and the metacone, being a buccal cusp and thus less worn-out than the lingual for the upper molars, still preserves part of its original development. A big wear facet, lying on the occlusal edge, has cancelled possible grooves which individualized the face lobes of the face, which looks rectilinear in the occlusal side, as we have seen before. The full development of the distal-buccal root is visible, as well as the point in which this detaches from the lingual root: this occurs halfway of the 3rd middle, at the same height in which the buccal roots separate.

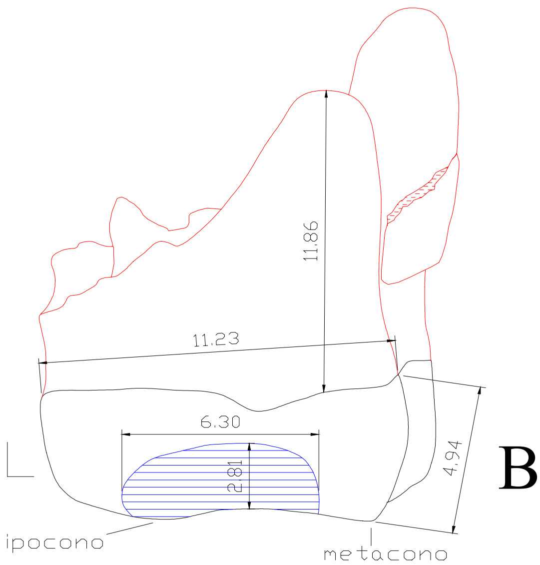


Fig. 12

5.3 MORPHOLOGICAL DESCRIPTION OF THE LOWER M1 AT TADDEO CAVE (fig. 13)

The lower right M1 of Taddeo Cave shows a less worn-out crown (degree C according to Lovejoy scheme), however a big part of the root is missing. Even here one sees, at 1,70 mm from the cervical line, a thin line of hypoplasia around the crown. Moreover, there are some pits in proximity to the ipoconulide.

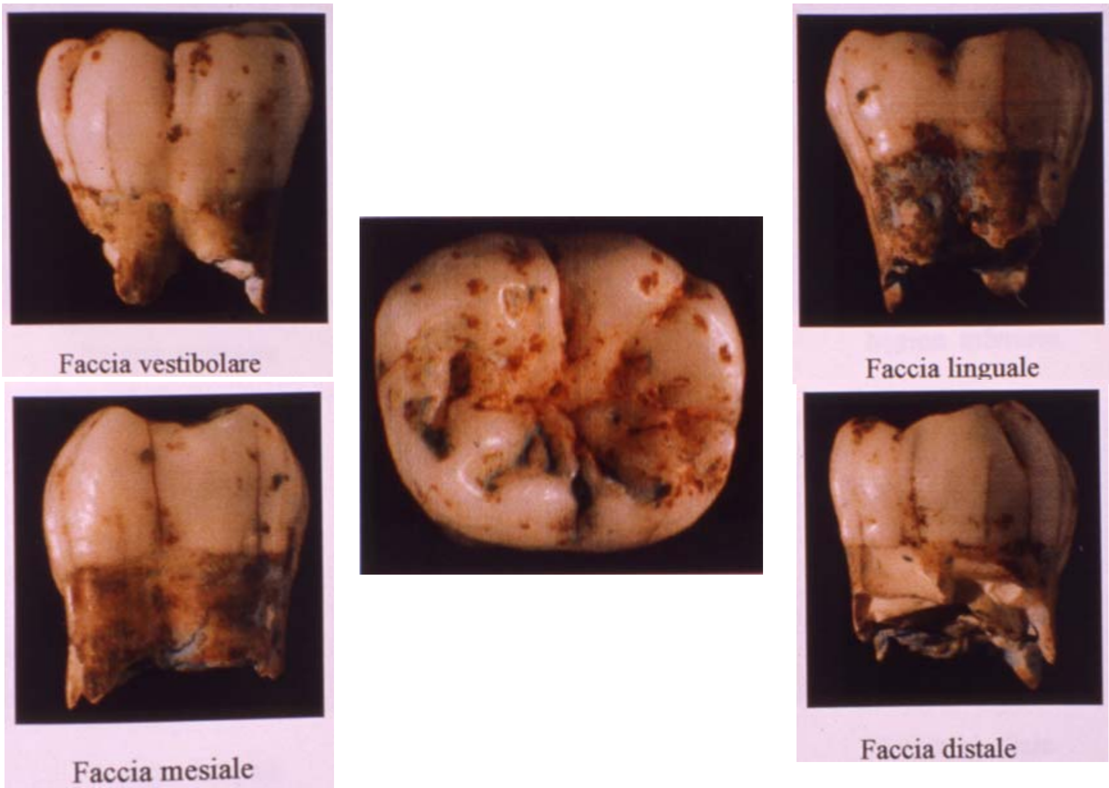


Fig. 13

5.3.1 BUCCAL FACE (figure 14)

The face observed from this side can be inscribed in a trapeze with big upper longer base. The occlusal edge is subject to a trilobate scalloping, of decreasing magnitude in mesio-distal direction, corresponding to the three buccal cusps: the protoconide, the hipoconide and the hipoconulide. Laterally, the mesial and distal edges are almost equally high and they medially converge downwards. The mesial edge is convex in proximity to the occlusal edge, while it is concave in the 3rd middle-cervical. The distal edge, instead, preserves its convexity in its entire contour. The cervical line, is basically rectilinear with a small invagination in proximity to the 3rd middle, shaped as a triangle with the point directed towards the mesial root (the same conformation as in the lower right M1 of Hortus II, although in our case it is slightly more protruding). This face is convex either longitudinally or transversally. In occlusal-cervical (longitudinal) direction, it is more convex at the 3rd cervical. Vertical grooves are present, coinciding with those of the occlusal surface. The mesial groove separates the protoconide from the hipoconide, and ends in a small hollow located at the 3rd middle of the face, emphasizing the contours of the lobes corresponding to the buccal cusps. The second groove, or distal groove, is a bit less deep than the first and separates the hipoconide from the hipoconulide, itself ending in a hollow, too. As the current and Neanderthalian M1s, this tooth has a mesial and a distal roots.

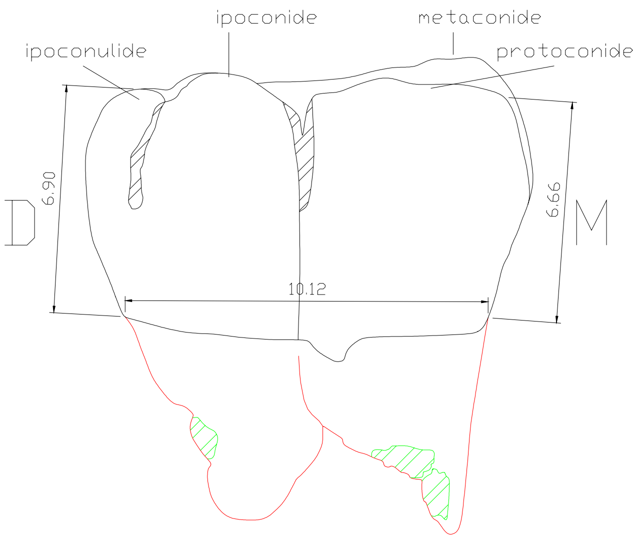


Fig. 14

Unfortunately, they are fractured, so it is impossible to describe their gait. Anyway, from the remaining portion it is possible to see their point of detachment, located at the 3rd cervical of the root, where a groove starts, to end in the cervical line.

5.3.2 LINGUAL FACE (figure 15)

The face is higher than the buccal in the 3rd mesial; the mesio-lingual cusp (metaconide) is more protruding than that disto-lingual (entoconide). This face, too, can be inscribed in a trapeze with big longer base, less wide than the buccal one. The asymmetric cusps, separated in the centre by a big groove (central-lingual groove), scallop the occlusal edge. This groove descends as a hollow into the lingual face until the 3rd occlusal, dividing the cusps in big lobes, almost identical to one

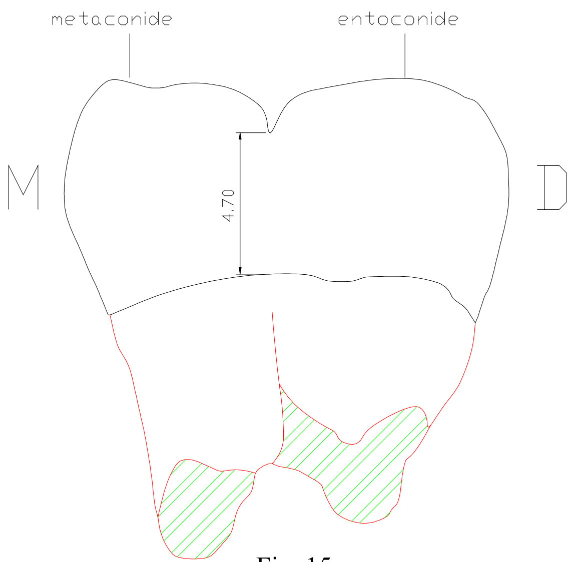


Fig. 15

another, and moving as far as the root. The depth of the groove and the scarce levelling of the cusp, emphasize how the tooth was subject to a little wear. Both lateral edges, the mesial higher than the distal one, are convex, with a tendency to converge at the base starting from the 3rd middle-cervical. The face is mesio-distally convex, as well as in occlusal-cervical direction, though in a less marked manner than the buccal face. The cervical line is slightly wavy, with a slight coronal convexity (similar to the lower right M1 of Hortus V and II, or also of the current man, in which the little coronal convexity formed, appears shifted towards the distal root). The remains of the root show – in the 3rd middle - the portion of the common stump, in which the roots are fused and grooved by a hollow that reaches the cervical line.

5.3.3 OCCLUSAL FACE (figure 16)

The occlusal face can be inscribed in a trapeze with a longer buccal base. The buccal edge is convex; the grooves divide the convexity in three distinct parts, corresponding to the three occlusal-buccal cusps. The lingual edge, slightly shorter, is also less convex and divided by an only groove. The mesial edge is convex, and like the distal, however narrower, recesses lingually. From the longitudinal groove (mesio-distal groove) towards the lingual one, the distal edge faithfully mirrors the mesial contour: this is due to the similar conformation of the margins of the metaconide and the entoconide. The cusps, five altogether, are fully preserved, and the wear has slightly etched only the protoconide apex. The cusps are buccal (protoconide and hipoconide), one is buccal-distal (hipoconulide), and others are lingual (entoconide and metaconide). Dimensionally speaking, the decreasing order is the following:

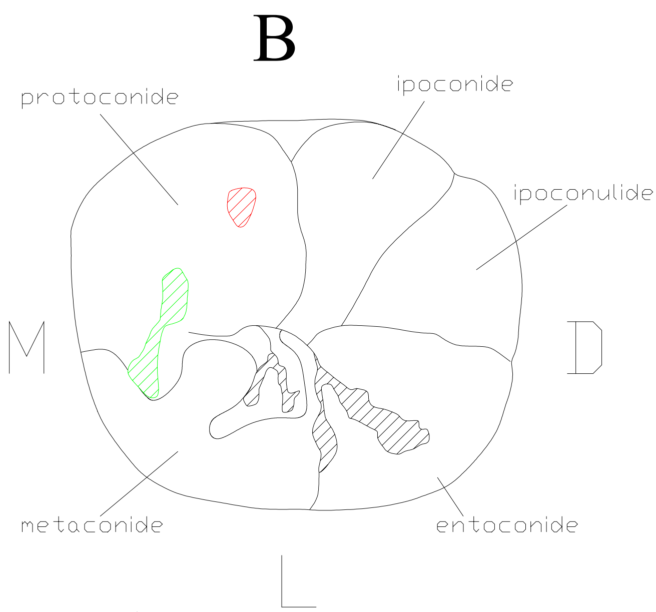


Fig. 16

protoconide>metaconide>entoconide>hipoconide≥hipoconulide

quite similar to the lower right M1 at Châteauneuf 2, showing the following sequence:

metaconide>protoconide>entoconide>ipoconide>ipoconulide

while among the lower current M1s the following order is frequently found:

metaconide>entoconide>protoconide>hipoconide>hipoconulide

from which it is assumed that the entoconide (or lingual-distal cusp) has overtaken the third place it had in the first sequences, the second of which is certainly ascribed to a Neanderthalian. The intra-cusp grooves are very noticeable: the longest one is the mesio-distal groove which separates the buccal from the lingual cusps and develops in proximity to a anterior fovea, longitudinally crossing all the middle surface of the tooth, just to end into the distal edge, as there is no posterior fovea to hold it. Both the buccal transverse and the cross-lingual grooves converge towards the centre of the occlusal surface, reaching the mesio-distal groove and causing the typical Y-shaped design (or dryopitecine), a plesiomorphic feature, which can be seen nowadays in some lower M1s. The metaconide connects to the protoconide through the anterior fovea, and moves towards the centre of the occlusal face, stopping at the margin of the mesio-distal groove, with a relevant transversal crest. From here, an enamel bridge starts, bordering on the distal margin of the anterior fovea, which flows at the base of the protoconide. A smaller crest, assimilable to another enamel bridge, connects the distal portion of the metaconide (in proximity to the transversal lingual groove) to the basal apex of the hipoconide. It is peculiarly in these situations, where the metaconide tends to seep between protoconide and hipoconide that the typical dryopithecine design generates. Even the entoconide pushes towards the centre of the occlusal surface with a transversal crest, relating to both the hipoconulide and the hipoconide.

5.3.4 MESIAL FACE (figure 17)

The occlusal edge is formed by respectively the oblique sides of the lingual (metaconide) and buccal (protoconide) cusps. The buccal edge clearly shows no trace of cingulum, displaying a very convex contour, not subject to interruptions, nor to levelling. The lingual edge, also convex, turns more rectilinear in the 3rd cervical, obliquely bending towards the cervical line. The cervical edge, rectilinear until the 3rd middle, forms a slight coronal convexity at the 3rd lingual. It is furthermore visible a small wear facet (hatched), superiorly bordered by the occlusal edge. Its tiny dimension confirms that the tooth shared a few time with the near teeth and, since it fell post mortem, this could have been caused by a death in young age. The mesial root is crossed by a well-marked, vertical middle groove. As in the most frequent conditions, it is evident that the buccal-lingual diameter of the root is bigger than the mesio-distal one.

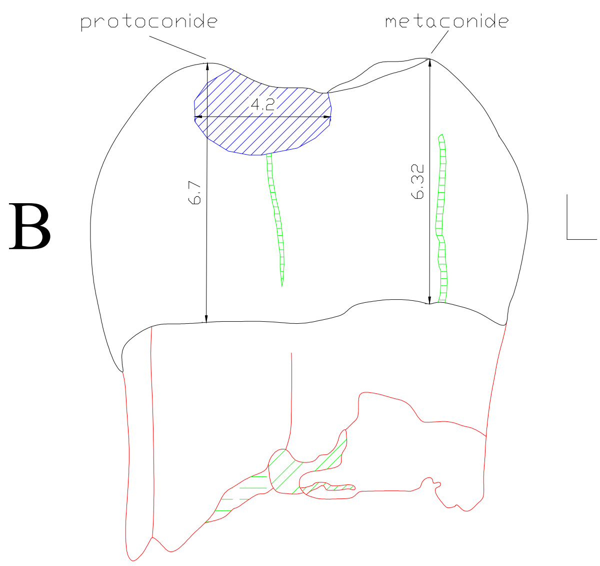


Fig. 17

5.3.5 DISTAL FACE (figure 18)

Three cusps are visible: lingual (entoconide), buccal-distal (ipoconulide), and buccal (ipoconide). The absence of wear fully preserves a "V"-like, wide-open occlusal edge. The buccal part is particularly convex, whereas the lingual one, convex from the 3rd middle, bends obliquely downwards towards the cervical line. The cervical edge is basically rectilinear. Red colour indicates the VL diameter, which I do not usually show, because not adequately performable in two-dimensional images.

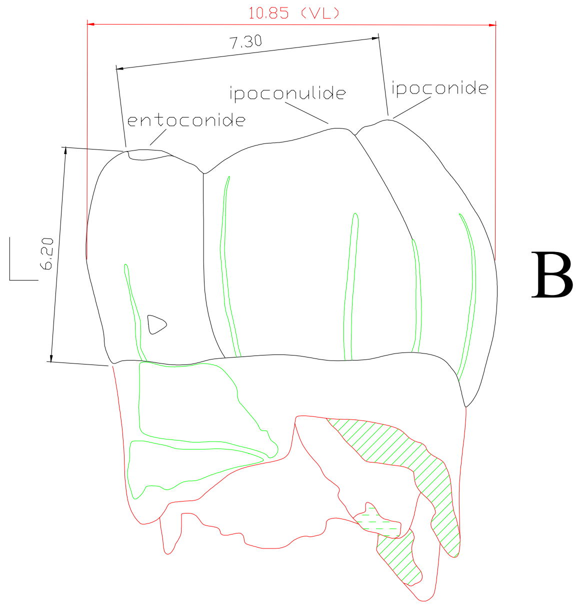


Fig. 18

CHAPTER 6

6.1 THE SAMPLE AND THE SCANNING TOOL

From the very first phases of research, one is aware of the limits of the 3D approach, which may be the reason why some researchers hesitate to exploit its potential abilities. A virtual database of scanned teeth is missing and those that do exist are reduced to a small number of samples that are not even usable for research purposes. Because of this, it is necessary to build a virtual database using samples of teeth from modern humans, which may not be representative of variations within our species, but this may be gradually implemented with future acquisitions. In order to elaborate a methodology of orientation and acquire some morphometric comparison information concerning a part of the crown that has not yet been fully investigated – that is, the part between the cervical line of tooth and the base of the occlusion surface – it is necessary to require samples of teeth from an anatomically modern human: 15 upper M1, with the same number of lower M1.

Since we need isolated mandibulary and maxillary first molars, we have selected a sample of teeth taken from a medieval cemetery[2]; in this way we avoid compromising the integrity of existing anthropological collections. Moreover, since we must determine a standard methodology of orientation, the gender of the sample teeth is not relevant.

The majority of scientific analyses that required a non-conventional orientation of teeth used unworn molars. This is a limit found when one uses partially worn or very damaged teeth, conditions that frequently occur in forensic and archaeological contexts.

The sample that we have selected is predominantly made up of teeth that are in a good condition and unworn, even if some molars, characterised by a small degree of wear (four inferior molars), have been considered on which it has not been possible to apply all the methods of orientation.

In order to fully understand if the new methodology of analysis may help to discriminate, using morphometric information, between samples from Neanderthal and anatomically modern humans, it is necessary to have a more representative paleoanthropological sample. If not, in fact, the results of the morphometric analysis (in the best hypothesis) can only highlight the difference – or not – between the small Neanderthal sample and the one from humans. With just one inferior Neanderthal molar (Grotta Taddeo) and 15 modern human samples, is the difference between the Neanderthal tooth and the comparison sample

[2] More specifically, locations that have been considered are S. Domenico (Forlì), Guidizzolo and Casalmoro (Mantova), that have already been studied from the points of view of paleodemography and palaeopathology.

statistically significant, without effectively knowing the variability of both dental morphometries? For this reason, it is necessary to augment the paleoanthropological sample without claiming to understand the range of variations within the species. In any case, an approach of this kind may help to provide more reliable results than those provided by a single tooth.

However, these results, too, must be evaluated with care, at least until we have a comprehensive virtual database of fossilised human species that may detail the variations of each species with a better rate of reliability. Therefore, some casts of Neanderthal and Modern Human teeth have been scanned (figure 1), the last ones referring to the Upper Paleolithic period, and kindly provided by Professor Erik Trinkaus of the University of Washington (St Louis, Missouri, USA). These have been entered into the following table:

Fig. 1. Neanderthal and Modern Human casts kindly provided by Professor Erik Trinkaus.

LIST OF FOSSILED TEETH		
Species	Lower M1	Upper M1
Neanderthal	Petit_Puy_3_right_ Devils_Tower_right Krapina_077_right Krapina_079_right Krapina_80_right Krapina_81_left Vindija_226_left	Spy_2_left Combe_Grenal_UNN_right Krapina_134_right Krapina_136_left Krapina_164_left Krapina_171_right La_Quina_18_right
Modern Human Upper Paleolithic	Les_Rois_R50_4_right Qafzeh_3_left	Fontéchevade_2_left
Case Study	Grotta_Taddeo_right	Grotta_Taddeo_right Grotta_del_Poggio_left

In this way, it has been possible to have a virtual database of M1 that, though small, allowed us to make interspecific comparisons. The casts have been scanned with the same system used for the molars of the modern human (medieval period), using a piezoelectric digitizer (PICZA), part of the equipment provided by the Laboratory of Anthropology at the University of Arkansas (Fayetteville, USA); the Laboratory is managed by Professor Peter Ungar.

6.2 THE SCANNING SYSTEM

To scan the teeth, we used a Roland PICZA PIX-30 piezoelectric digitizer, equipped with a stylus that is able to acquire approximately 400 points per minute (figure 2). Although the scanning time is quite lengthy, at about 90 minutes for each side of the tooth at a resolution of 0.1mm, the digitizer has some features that can prove useful for our research purposes. More specifically, the digitizer is non-invasive, so the fossilised sample does not have to be retouched. There are other scanning systems available, for example laser scanners, which use a very high resolution (0.01mm). However, the laser beam has difficulties in detecting reflective surfaces, for example the tooth enamel. For this reason, it is necessary to coat the teeth with talcum powder in order to dull any reflective surfaces. However, this process is invasive. The talcum powder can easily be removed and its use may not be visible on a determined tooth when performing a macroscopic exam. But this is different in the case of microscopic analysis (dental micro-wear, for example), as the talcum powder can enter grooves, wrinkles and tears within the tooth invalidating the reading of the dental wear, and the talc is difficult to remove unless we intervene invasively.

Fig. 2. Roland PICZA PIX-30 piezoelectric digitizer. From the Laboratory of Anthropology at the University of Arkansas (USA).

The scanning tool we used satisfies the following requirements:

1. <u>It is not invasive</u>. This is a very important condition, especially when the teeth to be scanned present paleoanthropological interests. Even if the stylus touches the surface to be scanned the contact is so minimal it does not leave any trace. The laboratory of anthropology at the University of Arkansas is equipped with a piezoelectric digitizer to scan small objects and a white light confocal microscope for the study of micro-wear. Therefore, it has been possible to experiment with the non-invasive feature of the piezoelectric digitizer. A small surface on the buccal side of a Neanderthal inferior canine tooth cast (Krapina 75) has been detected with a confocal microscope, before and after the scan made with the digitizer, with a magnification of 100X. As you can see from figure 3, the stylus of the scanner, in passing, has not left any trace.

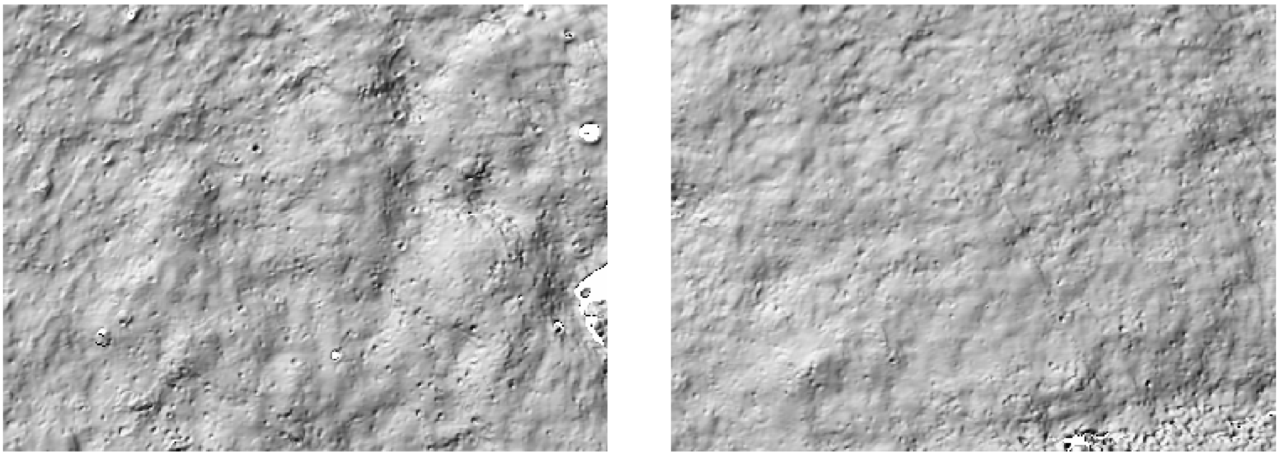


Fig. 3. Neanderthal inferior canine tooth cast (Krapina 75) detected with a confocal microscope, before (left) and after (right) the scan made with the piezoelectric digitizer. From the Laboratory of Anthropology at the University of Arkansas (USA).

2. Good resolution and precision. The scan must provide virtual copies of the tooth at a high resolution, with a precision of at least 0.1mm. Having a database containing scanned teeth at a higher resolution can be useful for the analysis of dental wear, such as those where the occlusion surface of the tooth is analysed using GIS programmes. In our case, a higher resolution would have resulted in much heavier virtual models without significantly improving the final outcome, because the metric differences between the teeth – those differences included in the intra and interspecific human variability where continuous and not-discrete variations occur – are such that a dimension such as the section of the crown is not significant under 0.1mm. As a consequence, we have decided to scan the teeth at a resolution of 0.1mm.

3. A good ratio between results and cost. It is evident that a microtomography system provides good results, allowing us to appreciate the internal structure of the tooth. However, the costs are very high and the internal structure of the tooth is superfluous information in the current research.

Therefore, the limit of the digitizer is the time used to acquire the different faces of the tooth, a time that is around 7-8 hours. In fact, to reconstruct the 3D geometrical model, the different faces of the object (in this specific case, the tooth), must be scanned in such a way as to expose a common area. This common surface will allow, in the next phase – called 'merge' – the super-position of these faces. The creation of virtual 3D models is, therefore, divided into different passages, each of them requiring specific equipment and software and much experience. In fact, if the scanning phase relegates the greater part of the job to the scanner, with the technician only having to position the object to be scanned in the most suitable way, the next phase – featuring the montage of the images – requires the knowledge of specific software and undoubted practical experience.

6.3 THE ACQUISITION

Each face of the tooth has been scanned and then merged to obtain the 3D model. Quality and ease of the montage depend essentially on how the tooth has been scanned. Since we have to build a virtual geometrical model on the basis of the acquisition of the single faces, it is necessary that these faces have a common superposition area, at least with the one we can define as ‘of reference’. To achieve this purpose, the best condition is reached by using the occlusion surface as a reference; therefore, every scanned face, except for the basal one, must have an area more or less comprehensive of that surface. The tooth must be positioned on the mobile board of the scanning tool using plasticine or a similar material and inclined so as to show both the part of the tooth that will be used to define one of its faces in the geometrical model and part of the occlusion surface. During the phase of ‘merge’, this will be super-positioned to the one of reference (figure 4).

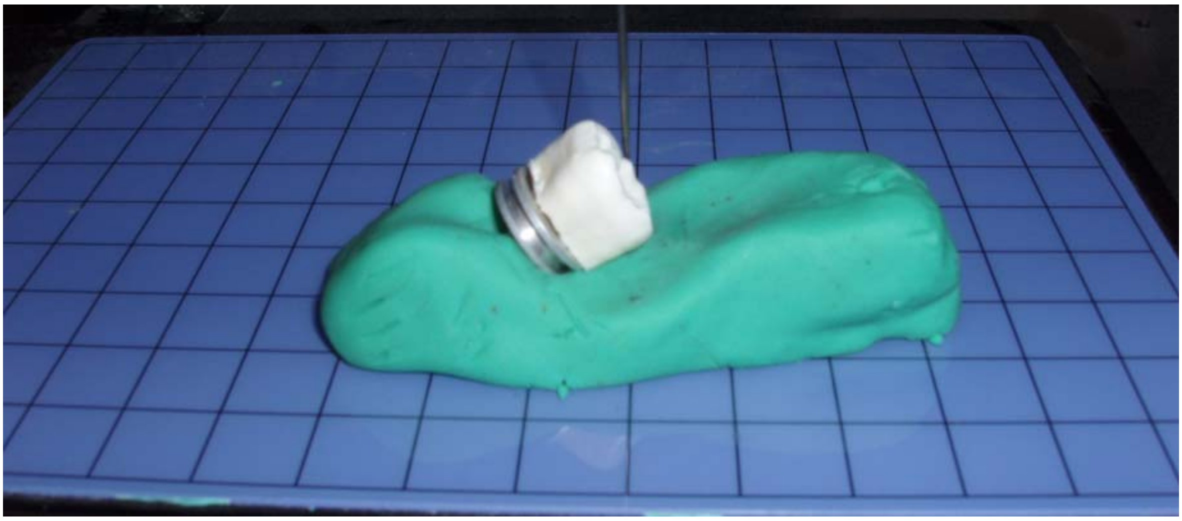


Fig. 4. Example of a Neanderthal molar (cast) positioned on the mobile board.

Six acquisitions are made for each tooth: the occlusal surface and the mesial, buccal, distal, lingual faces and an acquisition regarding the base of the tooth respectively, essentially at the top of the root in order to close the inferior aspect of the 3D geometrical model. When dental casts are present, in which only the crown of the tooth is usually shown, this sixth acquisition is not carried out.

6.4 THE 'MERGE'

All the pictures are imported in the 'merge' programme (the available software for Roland PIZCA PIX-30 is Pixform), and each picture is cleared of the points that do not define representative parts of the tooth. After this first approximate cleaning operation, the six faces are mounted (occlusion, lingual, buccal, mesial, distal and the one that we have defined as 'basal') and we keep the occlusion face as reference on which the other faces are mounted (figure 5).

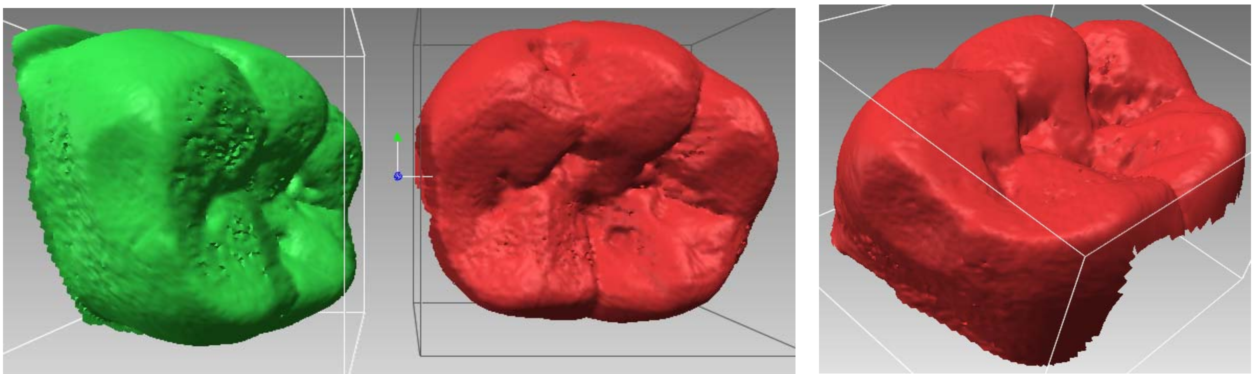


Fig. 5. Mesial face (left) and occlusal face (center) are merged (right)

Before the definitive merge of all the six faces into one 3D geometric model, it is necessary to clean any surfaces that exceed the superposition area. If not, in fact, problems may arise in the final phase of 'merge'. Then, after accurately checking that the montage has been correctly effectuated and that there are not parts that may need a further 'cleaning' or 'holes' (often caused by a mistake of the operator during the cleaning phase) it is possible to do the final 'merge' and obtain the 3D virtual model (figure 6).

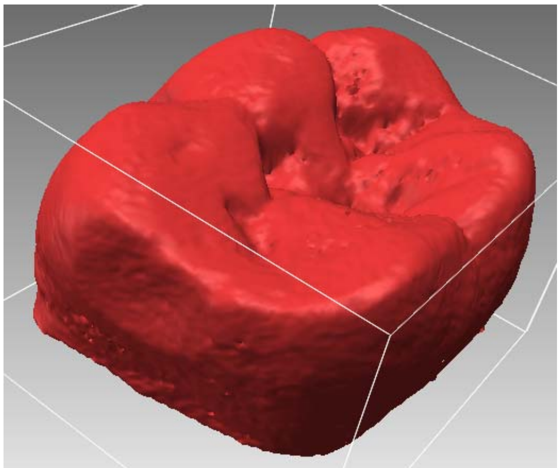


Fig. 6. 3D geometric model of a right lower molar

For casts, the 3D virtual reconstruction is simpler than that effectuated on real teeth, because the acquisition of the 'basal' view of the teeth is not present. As a consequence, not only is the time necessary for the scanning of the tooth reduced (due to five acquisitions instead of six per molar with root) but, in the montage phase, the base of the tooth is simply closed with a 'smooth', a substantially regular surface.

The missing root in the cast does not compromise the analysis that will be carried out hereafter, because the analysis concerns the crown of the tooth. It is evident, though, that a virtual archive (which is intended to be an easily accessible database for specific research or generic comparisons) is incomplete if it has teeth (in this particular case, dental casts) without a root. First of all, because the root is part of the tooth, and then because it provides very important information; it is no coincidence that some recent research analyzes the root via computerised tomography. On the other hand, we all know how difficult it is to have access to the original material; if the aim of the virtual database is to improve the spread of paleoanthropological remains and help break down barriers within this research sector, it is necessary to use the available material in this first phase. Again, we thank Professor Trinkaus, who provided us with casts of human teeth from the Upper and Middle Paleolithic periods that he made personally, because even if they do not respect the original idea with which the virtual archive was conceived (containing original teeth), they have been produced with extreme care and very definite details.

CHAPTER 7

7.1 STANDARDIZATION OF AN ORIENTATION SYSTEM FOR THE FIRST UPPER AND LOWER PERMANENT MOLARS

The possibility of morphometrically comparing objects generally depends on how these are positioned in the space. This is partly true, because some measures taken through landmarks that are specific and well definable on the object do not necessarily need a previous orientation of it.

We can therefore establish this first bipartition:

1. on one side there are those measures taken in correspondence of rigorous and easily recognizable landmarks (if we restrict the area of interest to the human skeleton, belongs to this group, for example, the distance between the two mental foramina;
2. on the other side there are measures in correspondence of landmarks determined by the specific orientation of the object (the skull length for instance, depends on the orientation of the skull according to the Frankfurt's plane).

There aren't many problems in the first group. The only limit comes from the degree of manifestation of the landmark (its expressivity), whose variability range is specific for that determined character, for the species taken in exam, and above all is usually without interruption.

Always restricting the exemplification to the human skeleton, in the skull the glabella constitutes an anatomic point which is easily recognizable when it's strongly protruding. When the degree of manifestation becomes lighter, although its area of interest is perfectly known, it becomes more difficult to distinguish the point with the same precision. Anyway the error done is light and above all we do not need to define a orientation system to recognize the point.

Nevertheless for other landmarks an orientation system is fundamental. If the maximum skull length measures the distance between the glabella and the opistocranion, I can not determine the last one if I haven't previously orientated the skull.

On the base of what I said we can make some reflections. There are several anatomic landmarks in the human skeleton that are easily recognizable, but there are as many where the identification depends on how the bone is positioned at the moment of study. We have seen that for what concerns the skull there is no particular problem, since there are several standardized orientation systems, among which the most used one is the Frankfurt's plane. On the contrary, there are no orientation systems for all the other skeletal segments and it's easy to guess that measuring won't never be precise. If this imprecision doesn't lead to gross mistakes, for example in the length measurements of the long bones, whose dimension (let's just think about the femur, the tibia, etc.) make the error negligible in the order of a millimetre, the same thing can't be said concerning all the other measures as diameters, widths and heights (taken through a calliper). In this case the bone is manually oriented and the small dimensions of the parts taken in consideration notably contribute to increase the importance of the error made during the measuring.

As reported in chapter 2, even in the traditional morphometric study of teeth the use of the calliper, as well as giving back limited information of the complex dental morphology, appears to be extremely imprecise because there are no standardized orientation systems of the teeth. More precisely I believe the error made in this case is bigger than that made in measuring the diameter in the middle of diaphysis of a long bone, firstly because there are several ways of doing the measuring and moreover because teeth, although they belong to very recognizable typologies, are highly variable.

We therefore understand that, in order to make an objective and innovative study on the dental morphology and morphometry it's necessary to define an orientation system for every single dental typology and we hope that in a near future this attention will be addressed to the single bone segments.

7.2 THE ORIENTATIONS: THE ACTUAL STATE OF KNOWLEDGE

It does not exist an orientation system conventionally recognized and the choice of a system rather than another rests on the discretion of the scholar, and anyway it's essentially restricted to the first and the second molar.

In the scientific works which resorted to the 2D image analysis, three orientation systems have been used. A method consists in positioning the occlusal tooth surface parallely (side by side) to the camera, so as to show the largest visible surface of the crown of the tooth itself (Robinson et al., 2002). A second method resorts to the cervical line, positioning the buccal cervical line (Bailey e Lynch, 2005), and sometimes also the distal one (Bailey, 2004) on a plane which is perpendicular to the optical axis of the camera. Recently, Kondo and Townsend (2006), on the base of a system proposed by Jukka e Lena (1999), but adapted to the first upper molar, position the plane identified by the three main cusps (paracone, metacone e protocone) perpendicularly to the optical axis of the camera.

In the 3D approach, while Zuccotti and others (1998), before scanning, position the tooth in the middle of a tablet with the buccal side parallel to the x axis of the tablet itself, without specifying a more precise orientation, Jukka e Lena (1999) make a rough orientation bringing back to the same horizontal plane the tops of the main cusps of the first lower molar (protoconide, metaconide and entoconide). The orientation suggested by Ungar and Williamson (2000) is effected after the scanning and so directly on the 3D tooth model, resorting to the three lower landmarks identified on the occlusal surface of teeth (Authors moreover underline that this method can be used for the worn out teeth too). We are precisely talking of lower points of the anterior and posterior fovea and of the point of contact between the crests that join the metaconide and the entoconide. In some works (Dennis et al., 2004; Ungar, 2004) molars have been positioned on a horizontal platform which approaches the occlusal plane. Teeth are then turned according to the mesio-distal and bucco-lingual axes through jack screws, until maximazing the occlusal tooth surface from on high view.

7.3 THE STANDARDIZATION OF THE ORIENTATION SYSTEM: A COMPARISON BETWEEN DIFFERENT SYSTEMS

The procedure directed to the standardization of the orientation system is divided in several phases:

- preorientation of the tooth;
- identification of landmarks;
- orientation of teeth along with the different alternatives suggested by several researchers and other methods here experimented for the first time;
- data elaboration and evaluation of the best orientation system for the first molar (upper and lower).

7.3.1 PREORIENTATION

Orientation systems mentioned above suppose the choice of some landmarks (cusps apexes, lower point of anterior and posterior fovea, etc.) or of "surfaces" of reference (buccal side of cervical line, maximum extension of the crown).

It's evident infact that in order to define an orientation system it's necessary to identify some landmarks. In the present work a preorientation of the tooth has been effected to make easier the identification of these landmarks. The digital model is imported as a "*.stl" file in a CAD program (Rinocheros) with the occlusal surface turned upwards. Selecting the upper view and therefore observing the tooth from on high, the next step is a model rotation in order to make the lateral views respectively correspond to the buccal, lingual, mesial and distal sides of the tooth. Once that, through the rotation, the four sides of the tooth have been well-defined, the next step of orientation will be restrained by balancing movements in bucco-lingual and mesio-distal directions respectively. We can justify the necessity of an appropriate preorientation right in the viewpoint of such a progressive reduction of tooth's freedom degrees.

If theoretically there are no problems, in practice the question is different. Depending on what can we objectively distinguish, in the upper norm, the tooth sides?

It has been judged appropriate to experiment a preorientation system based on two specific landmarks, even if in order to speed up the operation a previous orientation approximating the final position of the tooth has been anyway effected. In molars, both in buccal and lingual side, it is normally possible to observe an inflexion of the cervical line in the direction of the root bipartition (figure 1).

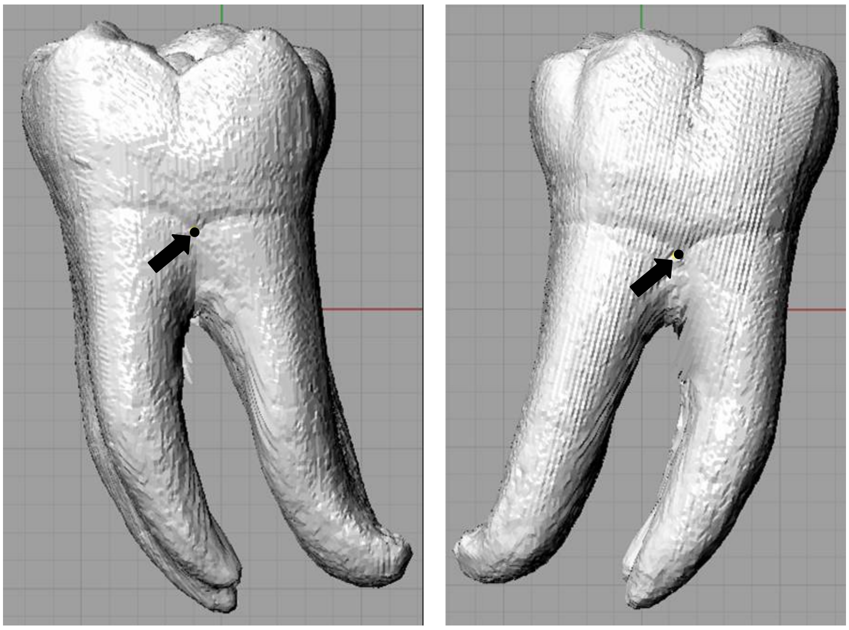


Fig.1. Lingual (left) and buccal (right) image of a first lower right molar. Landmarks are highlighted in correspondance of the point of cervical line maximum inflexion towards the root bipartition.

This is only partly true because there are many exceptions. First of all in the lingual side of upper molars the inflexion of cervical line, when it's present, is approximatively oriented towards the median axis of the lingual root. Moreover, not in all molars can be present a real inflexion ending with a point, but it can be observed a curvilinear trend of the cervical line with a root convexity, where the point of the curve maximum depth is oriented towards the bipartition mentioned above. Alternatively this trend can be more or less irregular, therefore not necessarily oriented towards he root bipartition, or can be also straight. When such an inflexion is highly evident and turned towards the bipartition, it is selected the point which corresponds to the inflexion apex (figure 1). When instead the trend is curvilinear, such a point will be chosen corresponding to the maximum root convexity of the cervical line.

When instead the cervical line is rectilinear or irregular (also in the cases when the root inflexion is clearly laterally moved), the useful point concerning the orientation shall be identified by the segment which links the upper point of root bipartition and the groove's lower point which, in the buccal side, divides the lobes of paracone/metacone for the upper M1 and protoconide/ipoconide for the lower M1, and in the lingual side protocone/ipocone for the upper M1 and the metaconide/entoconide for the lower M1 (figure 2).

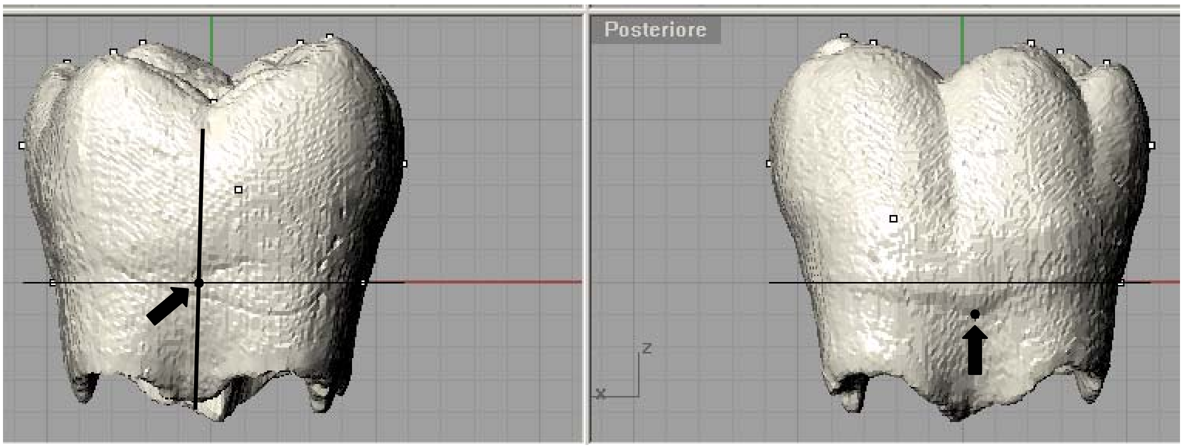
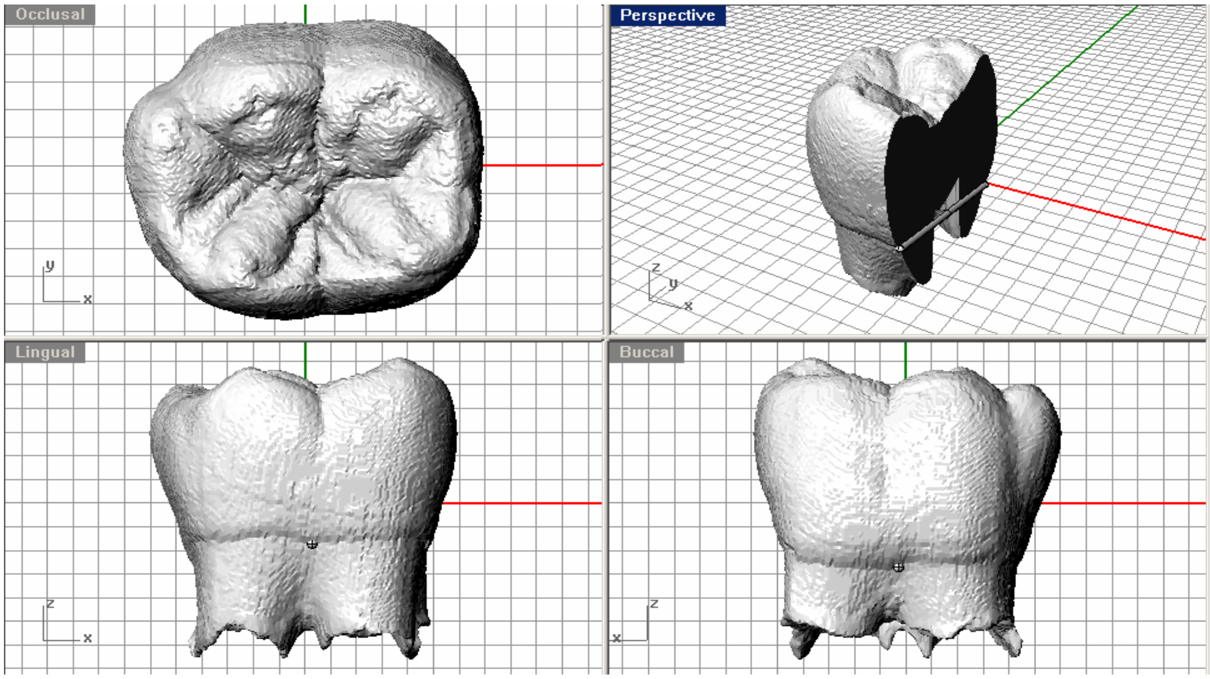


Fig 2. Left lower M1. In the buccal side (on the right), the inflexion of the cervical line in the middle of the face is clearly recognized. In the lingual side (on the left), the cervical point is identified by a segment connecting the lower point, in the lingual face, of the groove between the 2 major lobes (metaconide/entoconide) and the upper point of the root bifurcation.

By joining the two points identified in the cervical line of buccal and lingual sides, you obtain a segment that has been conventionally assumed as the axis for the tooth preorientation (figure 3). The segment will have a certain inclination which depends on the quote difference existing between the two extreme points. This inclination is not important for the preorientation because it is used as a point of reference the projection of the segment on a Reference Cartesian Plane.



Picture 3. Preorientation of tooth on the bucco-lingual axis. In the perspective image, properly sectioned, it is highlighted the segment obtained joining the two points useful for the preorientation.

To define the buccal, lingual, mesial and distal sides respectively, the geometric model has been turned until the projection on the Reference Cartesian Plane of the segment joining the two points was parallel to the Y axis figure 4).

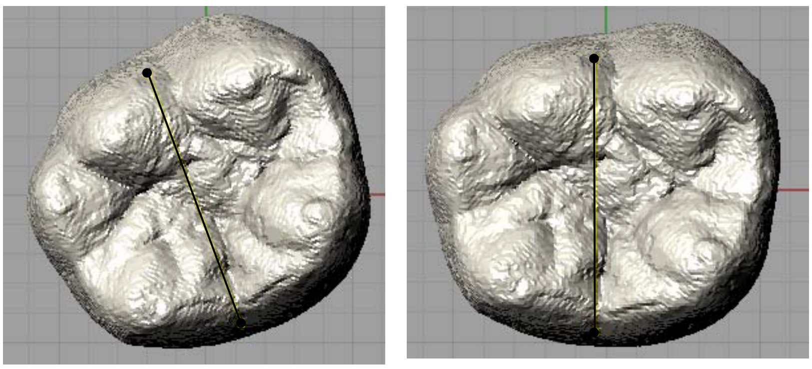


Figure 4. In the left image the first lower molar is not preoriented. Instead, in the right image the segment that joins the middle buccal and lingual point respectively to the cervical is parallel to the Y axis of the Reference Cartesian Plane: the tooth is preoriented.

7.3.1.1 PARTICULAR CASES

Anyway, despite all these considerations, there are many exceptions because the trend of the cervical line appears to be extremely variable. We have seen above that the inflexion of the cervical line in the direction of the root bipartition can represent a strong help for the identification of the two useful points for the tooth preorientation. In the cases of lack of evident inflexion, as well as in those where the cervical line's trend is rectilinear or shows a small curve, it has been suggested to use the imaginary line joining the groove which divides the main cusps, in the buccal and lingual sides respectively, with the higher point of root bipartition.

How to behave when the cervical line inflexion (on the buccal and lingual sides of the tooth), is considerably moved towards the mesial or distal side? It's a quite frequent condition, and in presence of integral teeth it is possible to decide if the use of these points brings about an incorrect preorientation. Let's think to the methods described above. Both in case we take as a point of reference the cervical line inflexion as well as the imaginary line that crosses the last one, in both cases the bipartition of the cusps constitutes an important reference. In figure 1 the two methods more or less identify the same points, because the cervical line inflexion actually lies on the line that joins the cusps dividing groove with the apex of the root bipartition. Anyway when the points identified on the base of the inflexion and of the imaginary line respectively are considerably different, it's clear that the preference goes to the second one. As a matter of fact this line is more connected to the tooth crown than the cervical line's inflexion, because it is identified starting from the lower point of main cusps dividing groove. Which laws regulate the cervical line trend? I suppose in fact it is more connected to the root than to the tooth's crown. Are we aware of the relationship existing between the root and the tooth's crown? Better, does it exist a morphometric relation between the two components of the tooth? If for example we consider the buccal side of a first lower molar, apart from the crown dimensions, the two roots could be more or less of the same size (condition where the cervical line inflexion should be set in the middle of buccal side, as in figure 5), but could be also considerably different. The figure 6 represents the virtual reconstruction of a neanderthalian tooth cast (Krapina 77, kindly given by professor E. Trinkaus). It is

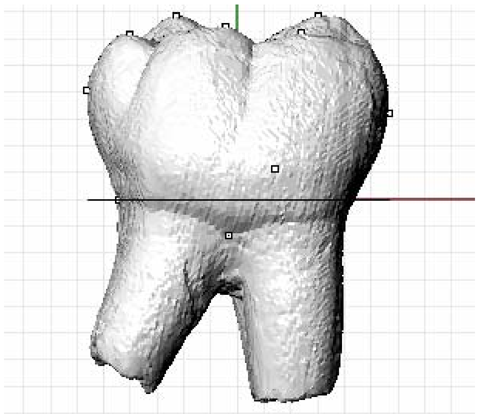


Fig. 5 First lower molar with roots of same size

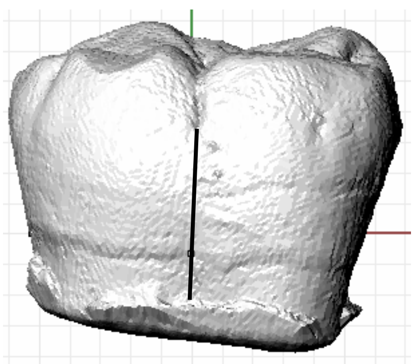


Fig. 6 Krapina 77

evident how the cervical line inflexion is notably moved in mesial direction. Moreover in this case the identification of the buccal point is further on complicated by the lack of root bipartition reference. These actually are limit cases, firstly because they are casts, secondly because they are not integral. Anyway, it is necessary to be able to use also this material, being aware of introducing a higher degree of subjectivity and to subsequently implement the error in the orientament procedures. Here below are reported the orientation results in the cases of use of the cervical line inflexion (right), or of the imaginary line originating from the dividing furrow of main cusps (left) (figure 7)

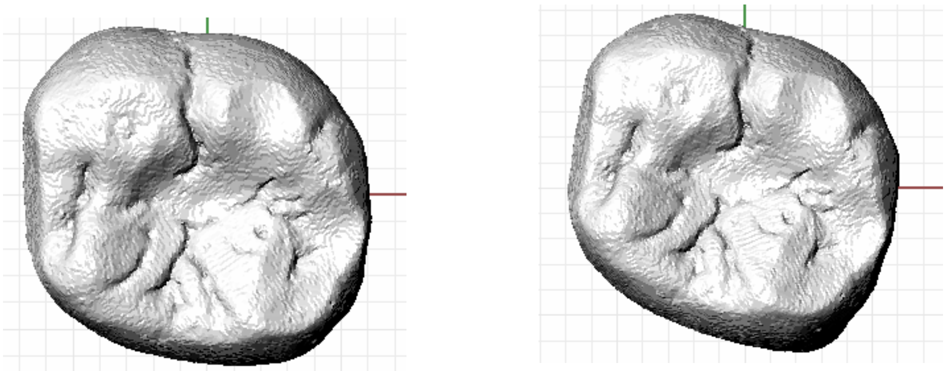


Fig. 7. Preorientation using the cervical line inflexion (right) and the imaginary line (left)

Using the cervical line inflexion the tooth appears to be more turned in the distal direction (clockwise). So, according to what said before, it is necessary to evaluate from time to time the characteristics of the tooth taken in exam. If the tooth is integral, and the roots are approximately of the same size, the cervical line inflexion (if present) should address itself towards the centre of the buccal and lingual sides respectively, and so give a result practically similar to that obtained using the imaginary line. Instead, in the cases of lack of inflexion or when it turns out to be too moved toward a side of the tooth, it is better to resort to the imaginary line.

7.3.2 THE IDENTIFICATION OF LANDMARKS

It is clear that the landmarks choice constitutes a fundamental part in the present research, even if the peculiar conformation of every single tooth makes it difficult to identify them: to this end the computerized approach intervenes in order to reduce the errors that can occur because of little objective considerations.

On the preoriented model a series of landmarks are then defined, besides the two already defined in the previous operation. The tooth can't anymore turn around its own z axis, therefore, selecting the different views (occlusal, mesial, distal, buccal, lingual) it is possible to define a series of objective points.

Orientation methods reported in scientific literature have often taken into exam the lower molars, so we can make use of some references for the landmarks' choice, generally selected on the tooth crown or along the cervical line. However not all points selected in lower molars can be recognized in the upper ones.

Here below is reported the list of landmarks identified in the lower molar; to these must be added the two points already selected for the preorientation (figure 8):

- Cusps apexes (1,2,3,4,5);
- The lower point respectively in the mesial and distal fossae (6,7) and the junction between crests connecting the metaconid and entoconid (8);
- Maximum external points of the crown (13,14,15,16);
- The middle cervical point in the mesial and distal side (11,12).

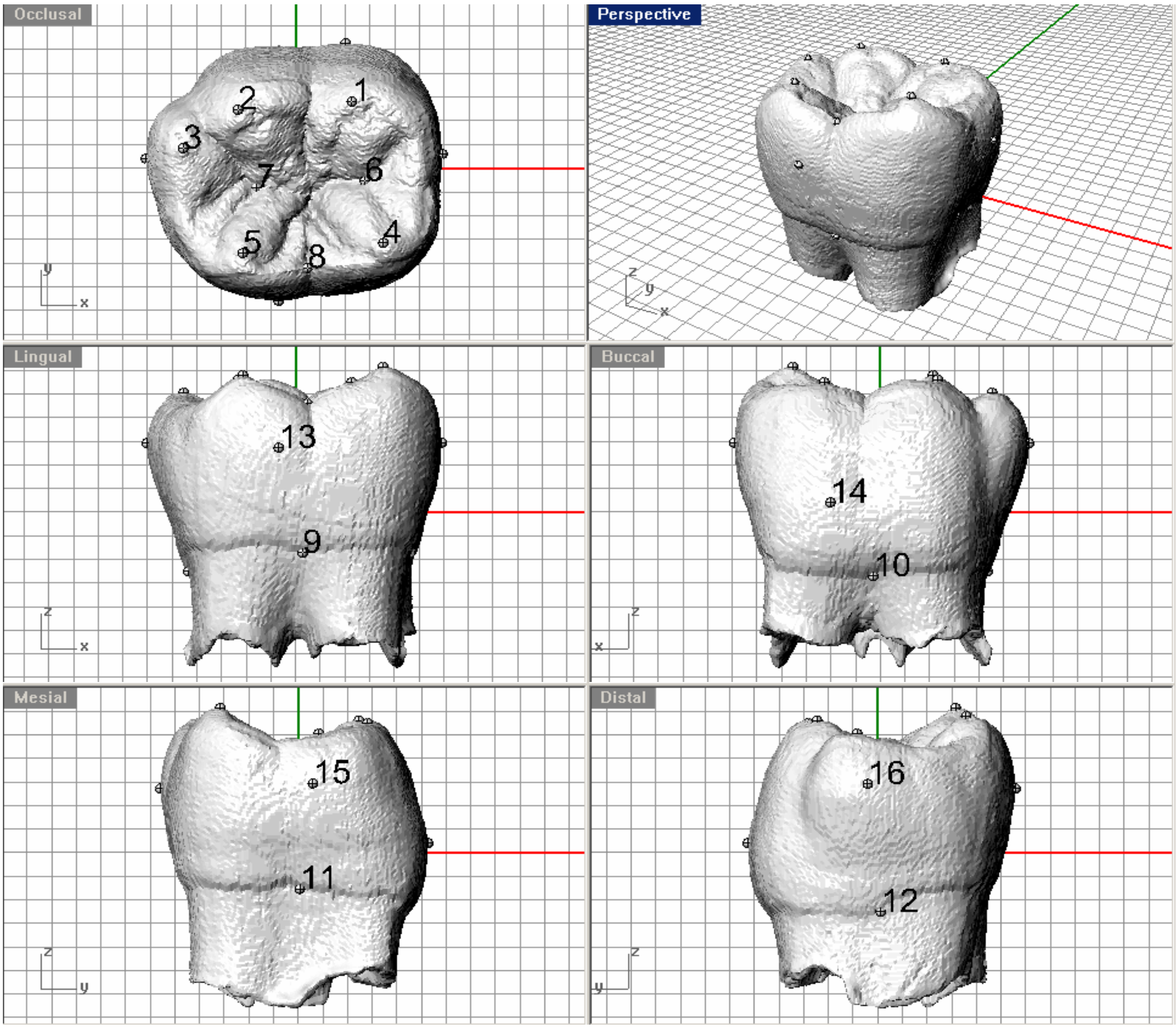


Fig. 8. Identification of landmarks in a first lower molar

The definition of middle points to the cervical line in the mesial and distal sides needs some clarifications. In order to make their identification more objective, it is taken as point of reference the segment built for the preorientation. More precisely, the plane perpendicular to this segment, passing through its middle point, crosses the cervical line in the mesial and distal sides and allows to determinate the two "middle" points on these sides (figure 9).

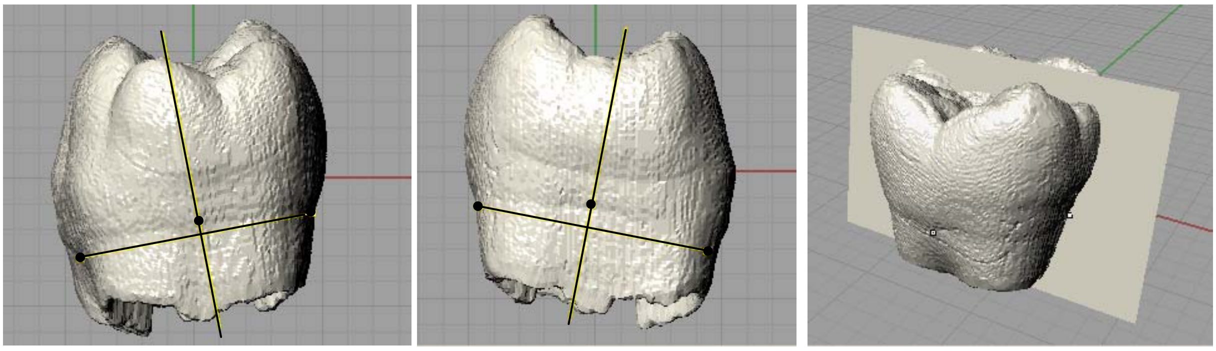


Fig. 9. Representation of the plane perpendicular to the preorientation segment passing by its middle point, in a left lower M1. From left to right: distal and mesial sides and axonometry.

With regard to this, it is important to notice that after the choice of middle points to the cervical line, respectively buccal and lingual, for the definition of preorientation segment (through the method described above), all other points are not selected at the operator's discretion, but have to conform to some criterions. After the preorientation phase the teeth sides have been defined, so it's possible to recognize a mesial and distal side. Infact, despite the tooth is not oriented yet, the plane passing by the middle point of the preorientation segment is approximately perpendicular to the crown inclination in bucco-lingual direction, respecting its trend. In the same way, the external points of the tooth are determined by a parallelepiped that builds up automatically exactly according to the maximum dimensions of the tooth itself. With regard to the cusps apexes, as well as the lower points of the mesial and distal fossae, the landmarks are quite objective and easy to identify on the virtual geometric model: they appear to be infact the highest points of the tooth (in the cusps) and the lowest ones in the fossae.

When it was possible the same landmarks have been identified on the upper molar following the same procedures used for the lower molar, especially concerning the definition of the two middle points in the cervical line, in mesial and distal sides respectively, and for the most external points of the crown. In detail, the upper molar landmarks, apart from those of the preorientation (middle buccal and lingual points to the cervical line) are as follows:

1. Cusps apexes;
2. The most external points of the crown;

3. The middle points in the cervical line on mesial and distal sides.

7.3.3 THE ORIENTATION SYSTEMS

Every tooth, after the preorientation phase, has been oriented according to the different alternatives suggested in the scientific literature; to these we added new methods, here for the first time experimented, essentially based on middle points identified in the cervical line. In table 1 are related all the orientation methods which have been used. Considering for example the first lower molar there are two methods which make use of the cusps apexes, a method is based on three points selected in the occlusal surface, four methods on the middle points to the cervical line and finally a method needs the points of crown maximum extension.

Orientation Methods	Landmarks		Reference
	Lower First Molar	Upper First Molar	
Pr-me-en cusps / pa-me-pr cusps	1,4,5	1,2,3	Jukka et Lena (1999)
Ip-me-en cusps	2,4,5	NA	*
mf-df-me/en	6,7,8	NA	Ungar et Williamson (2000)
l-m-d cervical	9,11,12	5,7,8	**
l-b-d cervical	9,10,12	5,6,8	**
m-d-b cervical	10,11,12	6,7,8	**
m-b-l cervical	9,10,11	5,6,7	**
ma-ex	13,14,15,16	9,10,11,12	Robinson et al. (2002)

*Modified by Jukka et Lena (1999): these used for the first lower molar : protoconide, metaconide, entoconide. Instead in this case ipoconide, metaconide, entoconide are used.
**Modified by Bailey et Lynch (2005) e Bailey (2004): these used the cervical line trend of buccal and distal sides. In this case instead are used sides middle points

Table1. List of orientation methods compared.

In the two central columns it is possible to go back to the number associated to the single landmark, as reported also in figure 8. In table 2 are indicated the abbreviations of landmarks' names, whose mention in following phases will be constant.

lower M1		upper M1	
pr	protoconide	**pa**	paracone
ip	ipoconide	**me**	metacone
me	metaconide	**pr**	protocone
en	entoconide	**b**	buccal
mf	mesial fossa	**d**	distal
df	distal fossa	**l**	lingual
me/en	metaconide/entoconide	**m**	mesial
b	buccal	**ma-ex**	max extension
d	distal		
l	lingual		
m	mesial		
ma-ex	max extension		

Table 2. Abbreviations

As pointed out in table 1, the majority of orientation systems needs three points, through which it is possible to identify a plane where the orientation is defined from time to time by the specific position of tooth in CAD program. In figure 10, for instance, it is shown a plane passing by the apexes of ipoconide-metaconide-entoconide (lower M1). We can compare the various orientation systems only if all the planes are projected, together with teeth, on a Conventional Reference Plane. With regard to this it was chosen the Cartesian Reference Plane and on it have been projected all the planes defined by the various orientation systems.

The method of the maximum external points of the crown seems to be different. In this case infact such points make it possible to identify two segments, one having a buccal-lingual direction, and the other with mesio-distal direction (figure 11). Since the teeth sides have been already defined through the preorientation, it is possible to work on orthogonal views, selecting the left lateral view, the right lateral one, and also the front and back view. Observing for example the tooth in lingual side (or in buccal side) it is possible to act on the segment that is perpendicular to these views, more precisely on the projection of the segment which links the maximum external mesial point to the distal one. This segment infact will have an inclination which depends on the position of the two external points. If we observe the tooth in lingual or buccal norm, we perceive just a grade, and it's on this grade that we have to operate. The orientation consists in this case of turning the projection of this segment, and then the tooth, on a plane parallel to that of the Cartesian Reference System.

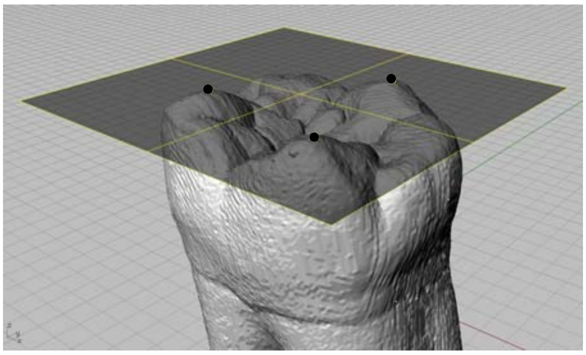


Fig. 10. Orientation system based on the apexes of ipoconide-metaconide-entoconide (right lower M1)

In the same way, selecting the mesial or distal view, the projection of the segment which joins the crown most external points, buccal and lingual, is turned (figure 11).

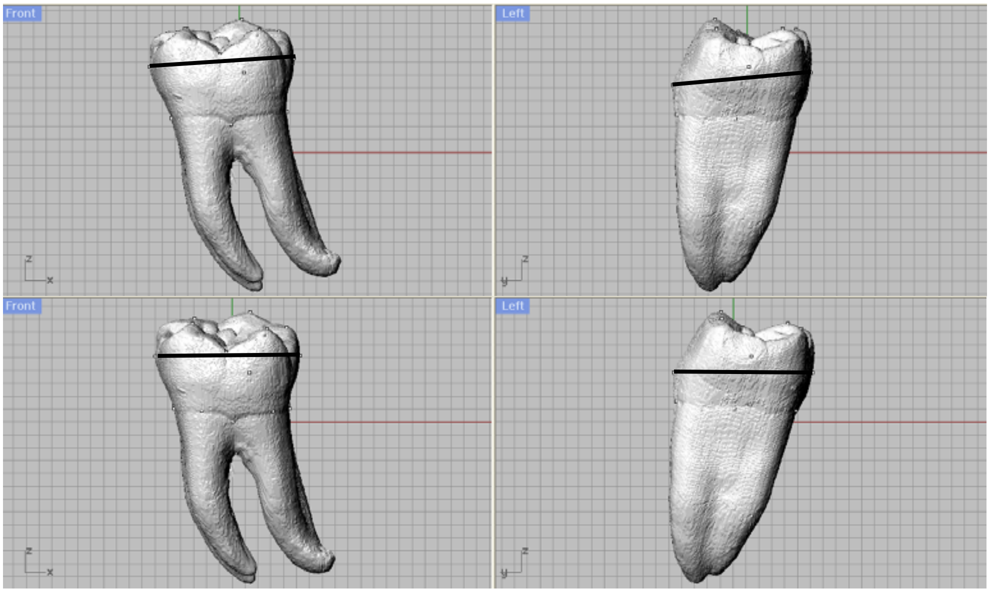


Fig. 11. Working in orthogonal view, you can rotate the tooth until the projection of each segment is parallel to the Reference Cartesian Plane

Here below are reported some pictures relative to planes built with the aim of orientation on first lower molar, on which is possible to compare a higher number of systems than those available for the upper molar. Anyway in both cases the phases remain the same: identification of landmarks, definition of the plane passing by three points (and of the segments joining the most external points of the crown), projection of these planes in the

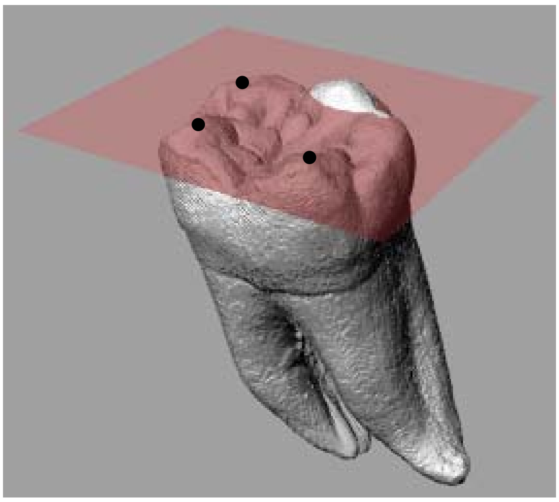


Fig. 12. Plane passing by pr-me-en points

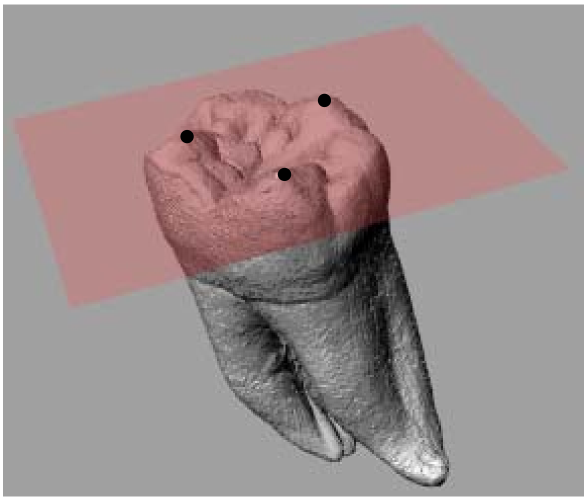


Fig. 13. Plane passing by ip-me-en points

Cartesian Reference Plane and rotation of segments until making them parallel to X axis of this Cartesian Reference System.

In figure 12, the plane passes by pr-me-en points, while in figure 13 it passes by ip-me-en points. The two joined pictures enable us to easily evaluate the different plane inclination with relation to the choice of a cusp (protoconide) rather than the other (ipoconide). In figure 14, the plane passing by the lower point of mesial and distal fossae and the point between the metaconide-entoconide crests is represented. Instead, in figure 15 the exemplification of a plane at the level of the cervical line passing by mesial-lingual-distal middle points is provided.

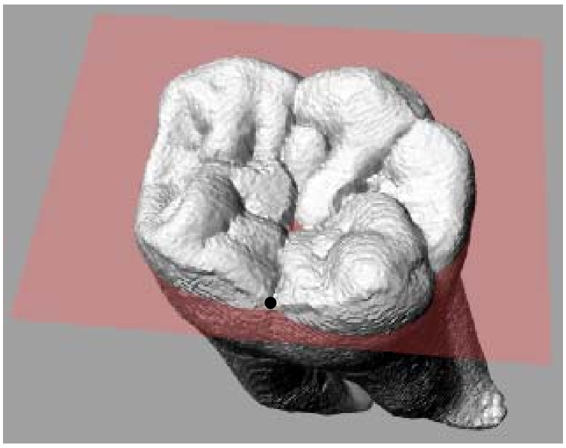


Fig. 14 Plane passing by the lower point of mesial and distal fossae and the point between the metaconide-entoconide crests (we reported its position with a black point)

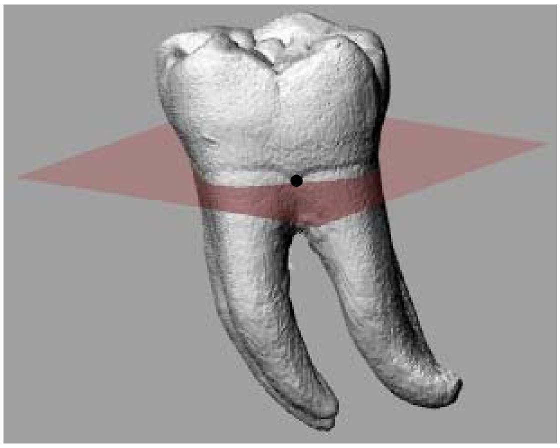


Fig. 15 Plane passing by mesial-lingual-distal middle points in cervical line (in the picture the middle lingual cervical point is shown)

7.3.4 DETERMINATION OF THE ORIENTATION SYSTEM

Once decided the modalities through which the orientation process is carried out, it is necessary to define the standards that enable to value the minor or major reliability of a system rather than others. In this case too, there are no significant contributes in the scientific literature, since the various orientation procedures have never been compared on the same sample. Moreover these systems have been used in researches where the area of interest is the tooth occlusal surface or the chewing one, and for this reason the orientation used mainly refers to the cusps apex and to the crown maximum visible surface in the occlusal norm. In the first case, it's implicit that the method can't be used in presence of worn teeth; instead, in the second case the procedure is completely subjective: how can I evaluate, without the help of control tools, if the tooth has been oriented so as to give back, in vertical norm, the largest occlusal surface? In scientific literature there are no references about it, with the exception of some articles which refer to the errors made during the measuring, where the orientation, among the variables considered, can hold a role not marginal at all (chapter 2).

Just for this reason, since more exhaustive indications are not available, the choices here made in relation to the characteristics which a valuable orientation system must have, are due entirely to our considerations on the tooth crown morphology.
As we have seen before, every single orientation used projects the tooth on the Cartesian Reference Plane, or, in case of the maximum extension of the crown, the projection of the segment which joins the opposite points is made parallel to this Plane. But it’s clear that, in relation to the orientation model, the Reference Plane will cross the tooth in different levels: for example, in the case of the system based on the cusps apex, the tooth crown is almost totally below the Plane, whereas in the case of the orientation built on middle point to the cervical line, the tooth crown is almost totally above it. (figure 16). It is therefore necessary to define a point of reference and on its base overlap the various orientations. To this end it has been judged convenient to resort to middle-lingual point to the cervical line.

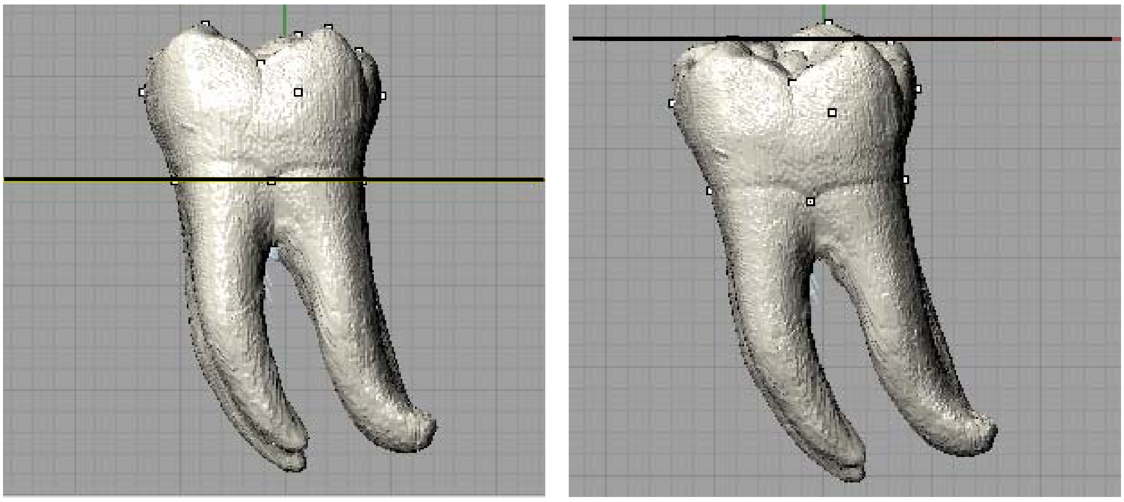


Fig. 16. Exemplification of the relation between the plane and the crown of the tooth.

Afterwards have been determined two projection and a section for every oriented tooth (figure 17):

1. a tooth section at the level of middle-lingual-cervical point (the landmark used both for preorientation and teeth overlap) parallel to the Cartesian Reference Plane (S);
2. the projection of the occlusal polygon (OP) on the Cartesian Reference Plane, obtained joining the cusps apexes;
3. the projection of the crown occlusal profile on the Cartesian Reference Plane (CP).

The three profiles thus obtained and the geometric centroids that these profiles delimit refer to different parts of the crown. The section (S) is infact relative to the lower portion of the crown, while the polygon (OP) to the upper one.

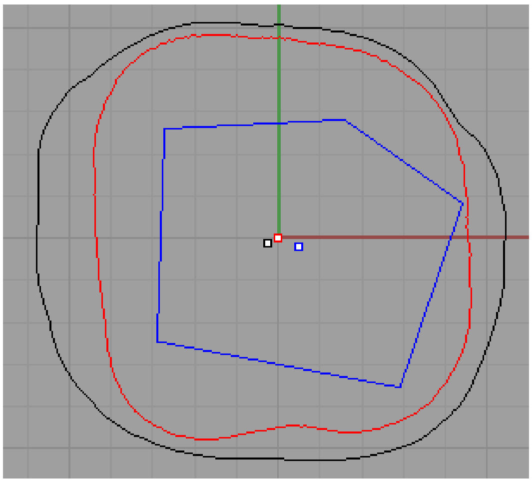


Fig. 17. Projections and section in a right lower M1. Centroids are also provided.

The projection of the crown's occlusal profile (CP) on the Reference plane is instead relative to that part of the tooth included between the two previous ones. More precisely, it is the profile normally used in the 2D image analysis, both indirectly, in order to value through a visual approach the maximum surface of the crown for the orientation, and directly for the tooth analysis, measuring its total area and dividing it on the basis of cusps surface. In our case, CP represents an intermediate portion of the crown. However it's important to underline once more that we are not talking of a section, but of a projection. For this reason what is reported in the profile is certainly relative to points of the tooth positioned at different heights. The maximum expansion of the crown in buccal side is situated at a lower level than the lingual one. Less significant is the difference between the points of maximum mesial and distal extension. Anyway these points certainly are at an intermediate level between the cusps apex and the middle-lingual point to the cervical line. The three profiles therefore define in an extremely synthetic way the most important parts of the whole crown. Taking as reference the figure 18, the tooth crown has its base on S, then it widens reaching the points of maximum expansion (CP), and finally it decreases finishing the vertical growth in correspondence of the cusps apex (OP).

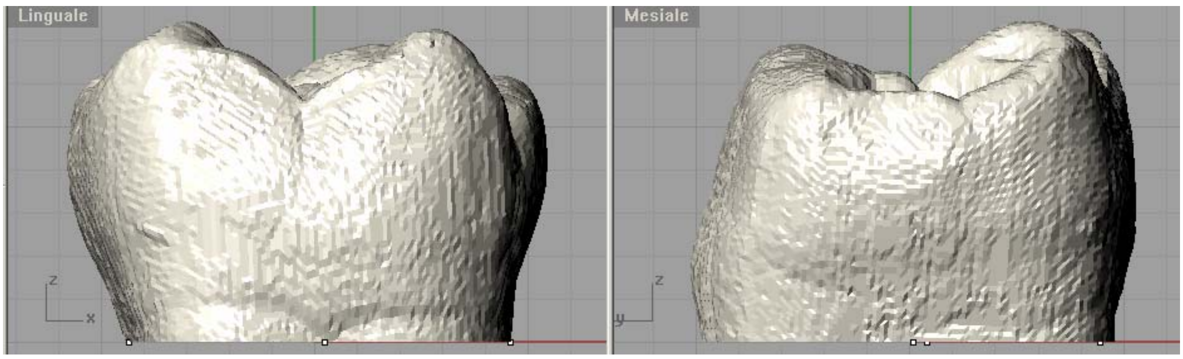


Fig. 18. Lower M1 crown: hypothetically we can assume S as the base of the crown, OP the end and CP represents an intermediate portion of the crown

If we consider the centroids of these three profiles, as reported in figure 17, the ideal orientation condition is that of coinciding centroids, a condition where the different parts of the crown tend to dispose themselves along its fictitious “z” axis. In best cases, S is contained in CP, as well as OP is contained in the section profile. On the contrary an inclined tooth normally gives back an OP which comes out of S, and the section itself can go beyond CP profile.

On the base of these considerations, it appears to be valuable the orientation system which shows the closer centroids. In order to compare and quantify the distance of the centroids obtained in the different orientation systems, it has been calculated the surface of the circle having as its diameter the segment which joins the most distant centroids (figure 19).

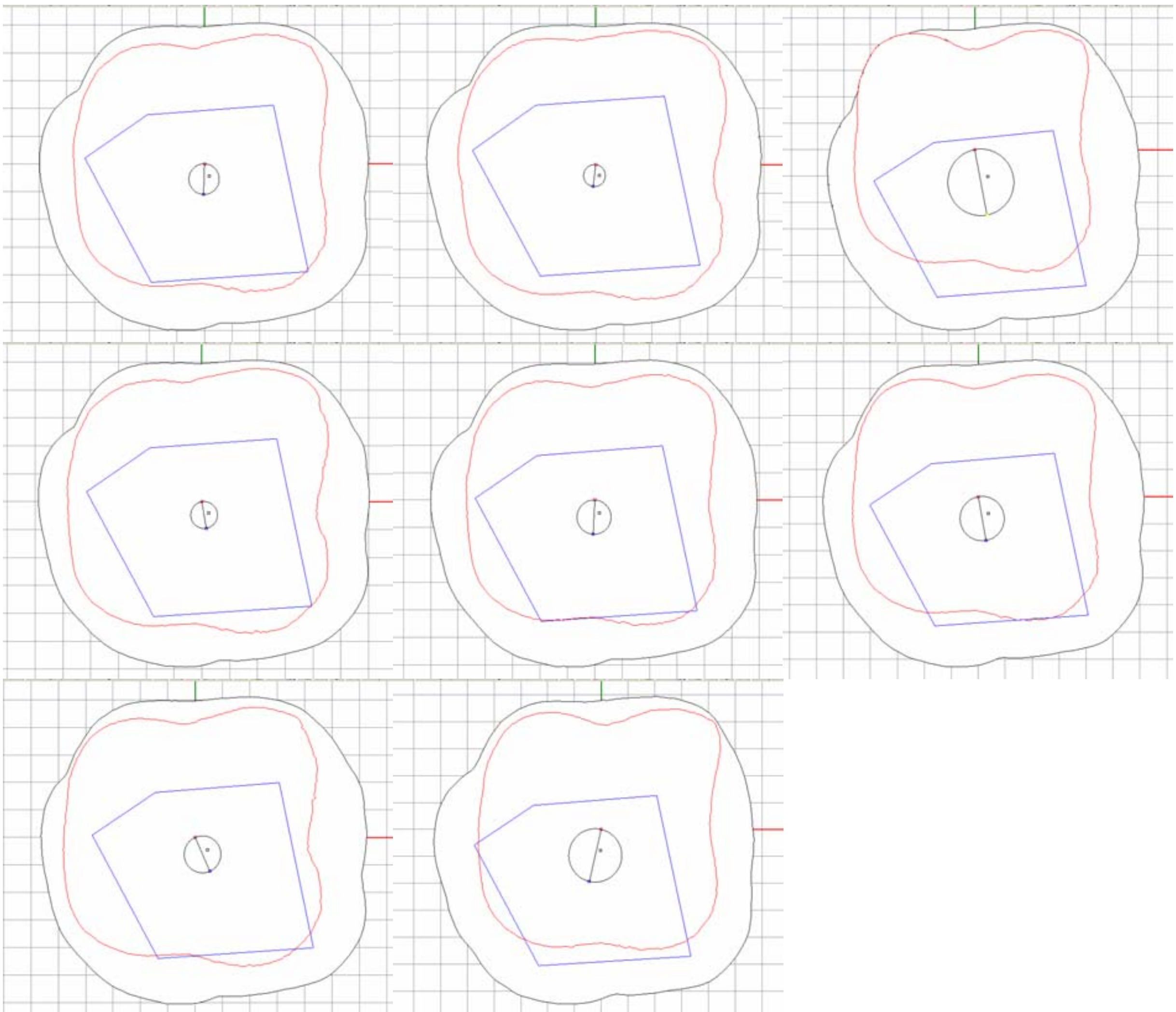


Figure 19. The eight orientation systems in a lower M1. Projection of the crown profile (CP) in black, tooth section identified at the level of the cervical line (S) in red, projection of the polygon (OP) in blue and circle (C) having as its diameter the segment which joins the most distant centroids. From left to right (starting from the top) the sequence of the pictures follows the order shown in table 1.

It is now necessary to make separated reflections for what concerns lower and upper molars. Infact, if the different phases that constitute the definition of a valuable system orientation are practically the same, now others factors, which depend on the morphological characteristics intrinsic of the specific dental typology, are taking over.

From figure 19, relative to a lower M1, emerges that in relation to the kind of orientation used, the more significant modification are perceived in the external limits of the crown, in vertical sense, at the level of the section and the polygon projection. Consequently, unlike the centroid of the CP profile (whose movements are more limited), their centroids suffer the greatest variations and they often determine the circle's diameter. However it's not a rule, and so there are many exceptions where the centroid of the CP profile turns out to be one of the most distant points.

In the same way, also in the upper M1 the more variable centroids are those relative to the polygon and section surface. Nevertheless, unlike lower M1, the variability is less marked, the three centroids are very close and can more frequently happen that one of the points which define the circle diameter is the centroid CP. Anyway, in the majority of cases the polygon is set inside the section and the circles are of small dimensions.

7.4 FIRST LOWER MOLAR RESULTS

The orientation method based on the apexes of ipoconide-metaconide-entoconide (ip-me-en) provides the best conditions, with an average value of the circle area which is considerably lower than that obtained through the other methods (table 3, graphic 1).

					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
ip_me_en	13	,4162	,31136	,08635	,2280	,6043	,03	1,11
pr_me_en	11	,9191	,44653	,13463	,6191	1,2191	,40	1,76
fossae	15	2,0533	1,65599	,42758	1,1363	2,9704	,18	5,00
lmd_cerv	15	,6247	,46039	,11887	,3697	,8796	,08	1,90
lbd_cerv	15	2,2800	,90598	,23392	1,7783	2,7817	,94	3,88
mdb_cerv	15	4,9700	3,21431	,82993	3,1900	6,7500	1,40	14,40
mbl_cerv	15	2,4080	1,36000	,35115	1,6549	3,1611	1,05	6,41
max_e	15	1,5433	1,12420	,29027	,9208	2,1659	,35	3,93
Total	114	1,9624	2,01119	,18837	1,5892	2,3356	,03	14,40

Table 3. Mean values of the circles area relative to different orientation systems tested on first lower molar.

A variance analysis conducted by ANOVA, confirms us that the difference between the mean values of the single groups is highly significant (table 4).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	212,832	7	30,405	13,196	,000
Within Groups	244,241	106	2,304		
Total	457,074	113			

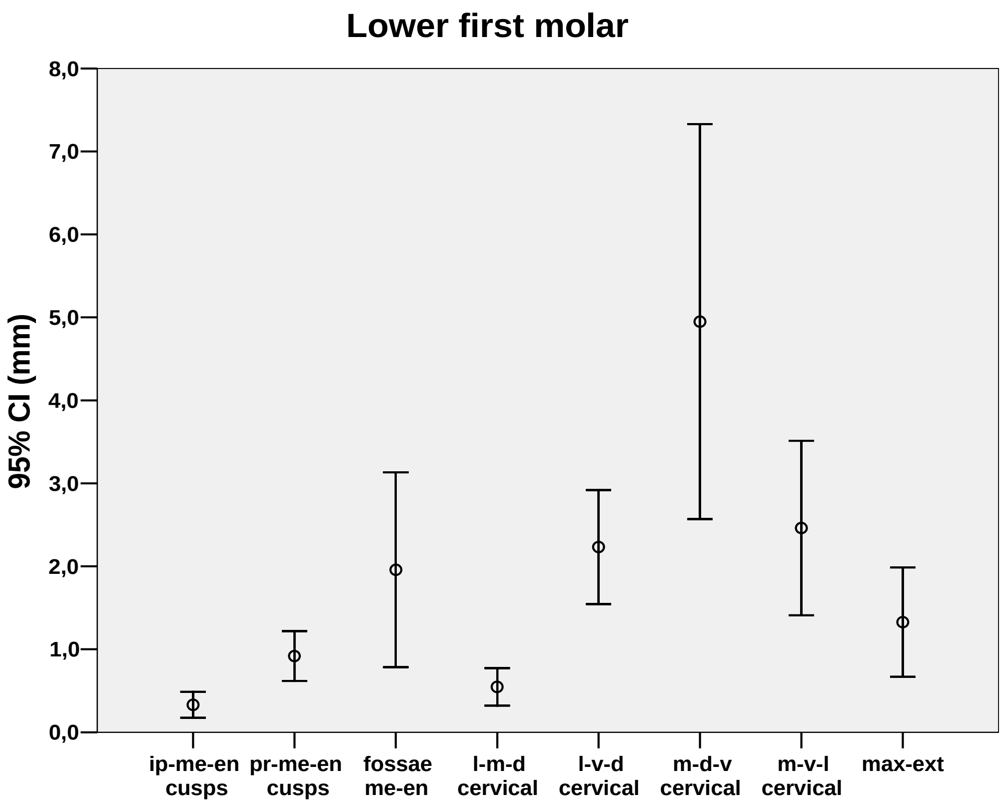
Table 4. Anova

It is interesting to notice that the method of cusps ip-me-en comes out to be much more reliable than that suggested in the scientific literature, relative to cusps pr-me-en which finally provides circles of higher dimension. But it is important to underline that the sample used in this latter analysis is smaller than that used for the other orientation systems, including the one of cusps ip-me-en, due to the dental wear whose effects appear first of all on protoconide. It has been therefore possible to have 11 samples for the pr-me-en method, and 13 for the ip-me-en one. The dental wear, when present, was generally light, but anyway sufficient to cancel the cusps tops. If the ip-me-en cusps method offers the best results, it is necessary to consider that the dental remains normally recovered in the paleanthropological record or in archaeological contests are often worn, condition that strongly affects both methods based on cusps. For this reason for the first lower molar the method defined by lingual-mesial-distal middle points on the cervical line (l-m-d) has been chosen.

Apart from the m-d-b method to the cervical line, whose mean value is extremely high with an high standard deviation, and with the exception of both methods to the cusps and of the method to the cervical line l-m-d which report quite low values (below one square millimetre) the other methods present mean values between 1,5 and 2,5 square millimetres.

Method l-m-d provides circles surfaces that slightly differ from those obtained through the method of ip-me-en cusps, but unlike the last one it is not invalidated by the wear processes that involve either the occlusal surface or the interproximal sides (which comes out after the tooth crown contact with the neighbouring ones).

The limits of this method are due to the cases where incidental diagenetic processes have deteriorated the enamel or the dentine at the level of the cervical line, or when this line is



Graphic 1. The simple error bars represent Confidence Interval (CI) for mean for separate variables of the first lower molar.

covered by tartar or destroyed by caries. But it's evident that there's a limit to the study of skeletal remains in general, and in particular of the dental ones, therefore the specific conditions which affect a correct reading of the cervical line, although they reduce the method's potentials, it is equally true that they cannot constitute an obstacle to its standardization. Considering for example the measuring of long bones, if on one side the procedures for the length survey have been standardized through the use of special tools conceived for this aim, on the other hand there is the awareness that in presence of bone fragments or incomplete parts of it, it is not possible to make this measuring. The same reflection must be made for the standardization of a new methodology for the teeth study. It is necessary to elaborate a method that can be used in the majority of cases, but accepting that there can be cases when the tooth can't be analysed, and therefore keeping open the perspectives of further developments in the new methodology. So the most current opinion is that the system based on the three middle points l-m-d to the cervical line provides, for the lower M1, the best condition for a proper tooth orientation. The significantly low mean value associated to a quite small standard deviation reflects a mild variability of the tooth inclination degree when these three middle points to the cervical line are used. So, as reported in the following chapter, do emerge new possibilities to effect traditional measurings and to define a series of innovative analysis which consider different morphometric aspects of the tooth crown, and through them it will be possible to have more morphologic information and to benefit of alternative parameters for the taxonomical definition of the species. If the results seem to be extremely interesting for what concerns the first lower molar and clearly define the best system which allows to orientate the tooth in the right way, it is also true that 15 teeth are a small quantity for the method standardization and consequently is necessary an implementation of the sample, considering moreover that in the cases of dental wear cusps method can not be applied.

Anyway these first results are very significant, and in the course of present work for the lower M1 it will be used l-m-d orientation system to study the first lower molar of Grotta Taddeo.

7.5 FIRST UPPER MOLAR RESULTS

Unlike the first lower molar, the six orientation methods tested on the first upper molar generally provide very close centroids and therefore very low mean values of the circles area (table 5 and graphic 2).

					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
pa_me_pr	15	,3147	,27594	,07125	,1619	,4675	,03	1,12
lmd_cerv	15	,6793	,52812	,13636	,3869	,9718	,08	1,87
lbd_cerv	15	,6687	,76385	,19723	,2457	1,0917	,08	2,29
mdb_cerv	15	,5020	,28474	,07352	,3443	,6597	,07	,88
mbl_cerv	15	,5373	,41325	,10670	,3085	,7662	,06	1,66
max_e	15	,8780	,79452	,20514	,4380	1,3180	,07	3,16
Total	90	,5967	,56340	,05939	,4787	,7147	,03	3,16

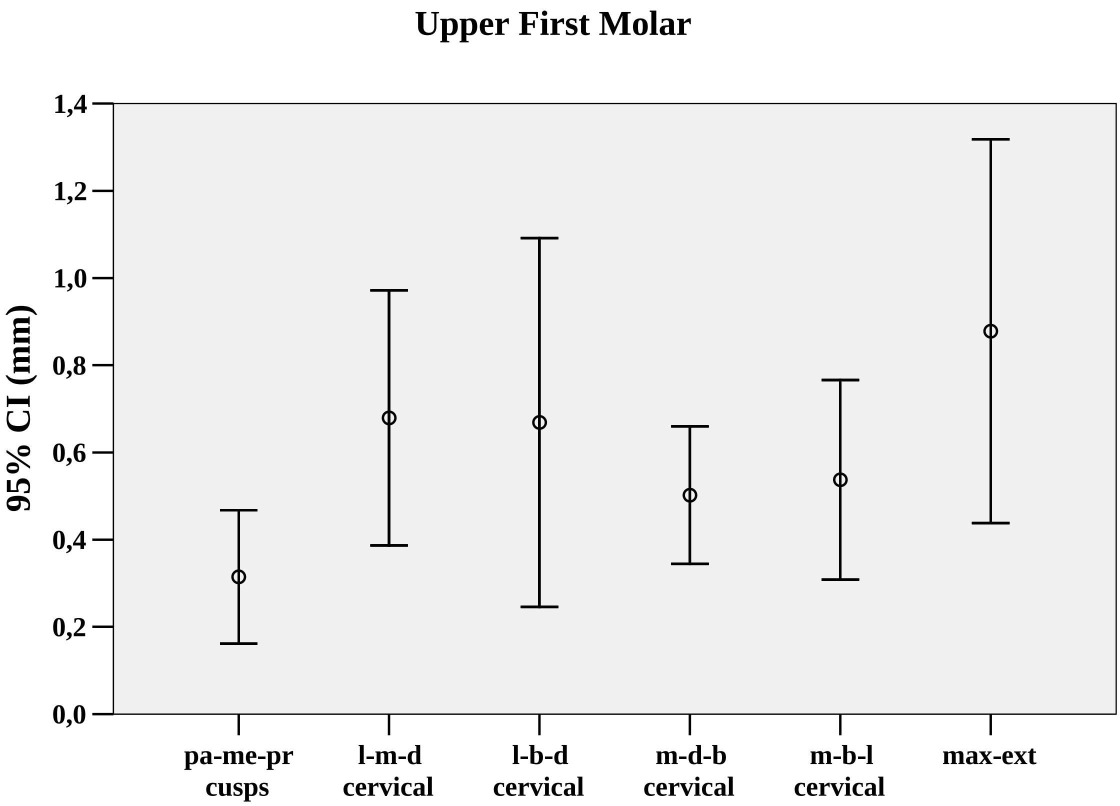
Table 5. Mean values of the circles area relative to different orientation systems tested on first upper molar.

So we can’t notice special differences between the single methods, as pointed out also by the result of the variance analysis (table 6), where the p value of test F doesn’t seem to be significant (p=0,120), therefore the choice of a method at the expense of another must be further supported increasing quantitatively the sample scanned.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2,748	5	,550	1,810	,120
Within Groups	25,503	84	,304		
Total	28,250	89			

Table 6. Anova

All methods infact show mean values of the circle area which are inferior to the square millimetre. In this case the standardization of the orientation method depends almost entirely on our considerations. Especially the method of cusps (pa-me-pr) shows surface values that normally go below a half square millimetre. However, if we consider, as we mentioned above, that cusps are easily worn, it is necessary to choose a method that is less affected by this process. If we observe table 5, it is clear that the points of maximum extension (max-ext) of the crown offer the highest values, both for the circle area and the standard deviation. Moreover they are easily subjected to wear. If infact the point of maximum extension of the crown in the buccal side is situated near he cervical line, and therefore less affected by wear, the other three points are instead hardly affected by this negative factor. Particularly mesial and distal points strongly suffer interproximal wear. Such wear appears immediately after the tooth eruption, so it can be easily found also in teeth having a minimum degree of occlusal wear. The only alternative is given once more by the points to the cervical line, the most distant from the occlusal surface and from the interproximal faces, for this reason less affected by wear.



Graphic 2. The simple error bars represent Confidence Interval (CI) for mean for separate variables of the first upper molar.

As reported in table n. 5 and in the graphic 2, the method which is closer to the cusps one seems to be that of mesial-distal-buccal middle points (m-d-b cervical).

Mean value infact are not only inferior to those provide by other methods, but also the standard deviation is practically the same of the one obtained with cusps method, indicating therefore that the variability of teeth orientation by means of m-d-b is not so relevant.

7.6 CONCLUSIONS

It has been often emphasized the necessity of standardizing an orientation system, since in the scientific literature different methodologies are suggested, but in practice we don't have any criterions to value any possible difference in the results of the single methods. Especially for this reason it is not possible to suggest which one among these provide the best performances.

Resorting to advanced technologies and innovative aspects (the projection of various orientation systems on the same plane, the section of the tooth at the level of the middle lingual point in the cervical line, determination of the area of the circle defined by the two more distant centroids, etc..), it has been possible to compare a series of methods and then choose the one that, according to our considerations, has the best requirements.

First of all it has been pointed out that there is a significant difference between the mean values of the circles area of lower M1, unlike what happens for upper M1 (p=0,120). Infact, whereas in the first case the variations of the orientation system can cause significant modifications of the tooth inclination which directly reflect on the variability of the circles dimensions, in the second case the movements are generally of little importance and so can't be noticed a significant variability in their dimension. Anyway in both cases it has been chosen the orientation method that provides smaller circles, apart from systems based on the apex of cusps which are too easily subject to dental wear: more precisely, the lmd system to the cervical line for the lower M1, and the mdb system to the cervical line for the upper M1.
All these considerations however are affected by an intrinsic limit due to the scanty sample used. It is evident the difference in the circles dimensions in the lower M1, as well as the minor variability in the upper M1. Consequently the choice made in the first case becomes more efficient and finds a better base; the second one instead becomes more uncertain. In both cases it is fundamental to implement the sample.

CHAPTER 8

8.1 TEETH ANALYSIS: THE USE OF A PART OF THE CROWN LESS SUBJECT TO USURY

Analysis are centered on the tooth crown, with the exception of a small portion of root near the cervical line. The aim is to investigate a part of the crown more hardly subjected to wear process and therefore more distant both from occlusal surface and, but not always, from interproximal faces. In the majority of cases infact the teeth recovered in paleoanthropologic settings show traces of wear. In the best of hypothesis wear slightly interests the apexes of cusps, even if generally these are heavily damaged. Wear infact is a degenerative process which interests the dental crown in the course of its chewing and pre-chewing functions, and often interests the maximum MD length of the tooth, so making the measuring of this diameter not very reliable. There are some differences between lower M1 and upper M1, but generally the tooth points of maximum extension in mesio-distal direction, as well as in lingual one, are in the third middle or at the beginning of the third distal of the crown, so towards the cusps apexes. Anyway they are more easily subjected to usury than the point of maximum extension set in the buccal face of the crown (figure 1).

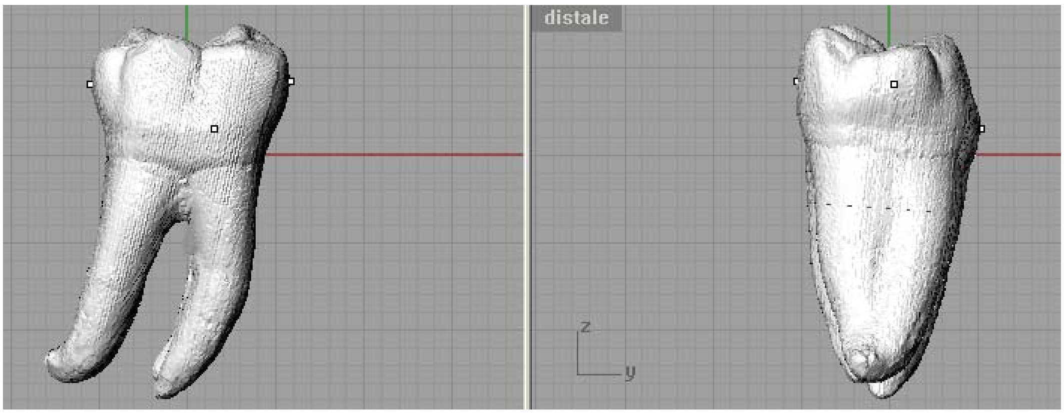


Fig.1. Maximum external landmarks in a lower M1

So, if the morphology and morphometry of the tooth crown can provide indications useful to taxonomic definition of the species and if the most interesting aspect, or at least the part of the crown that has been more used for the scope, comes out to be damaged by the destructive process of wear, a possible solution is to search the morphologic and morphometric characteristics of the crown near the cervical line, or at least in the area comprised between the cervical line and the base of cusps.

This possibility has become an object of research in the present work, so the analysis mentioned below refer to a part of the crown rarely interested by studies of morphologic and morphometric nature.
According to this and through Rhinos's command "multiple sections", from the middle cervical lingual point for the lower M1 and the middle cervical buccal point for the upper M1, multiple sections of the crown, parallel to the Reference Cartesian Plane and 1 mm far one from the other, have been carried out (figure 2).

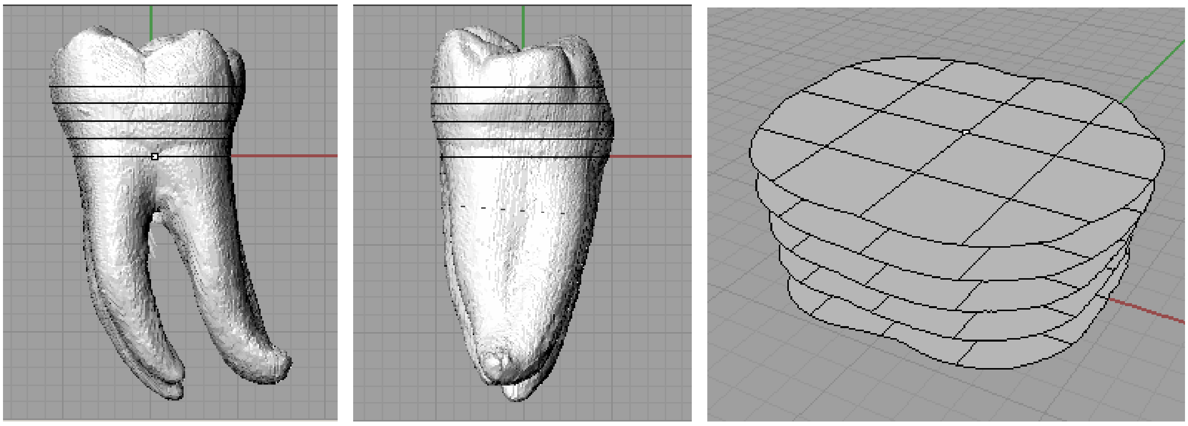


Fig.2. Multiple sections starting from the middle cervical lingual point (lower M1)

Three aspects can be pointed out:

4. The middle-lingual point and the middle-buccal point to the cervical line. As mentioned in the previous chapter concerning the definition of an orientation system for upper and lower M1 respectively, these points are identified for the operations of tooth preorientation. They therefore constitute the fundamental points on which depend the selection of the other landmarks on the crown and on the cervical line. So it is clear that, having to decide through which point to the cervical line it is better to set the sections, the choice could only drop on the middle-lingual for the lower molar and on the middle-buccal for the upper one, since they have already been used in the respective orientation systems.
5. Sections parallel to the Referente Cartesian Plane. This plane has been used for all the orientation procedures. On this infact all systems have been projected and various results have been compared. The two systems chosen, one for the upper M1 and the other for the lower M1 are parallel to this Cartesian Plane, and is therefore clear that the most objective method to section the crown is that of using planes which are parallel to that of Reference.

6. <u>1 millimetre far-between sections</u>. This “step” is considered sufficient with regard to the present research.

Five sections are made (numeration starts from the first section in correspondence of the cervical line), so the first 4 millimetres of the crown have been considered. The sixth section infact, set 5 millimetres far from the cervical line, is normally above the base of the occlusal surface, in a zone easily subjected to wear.

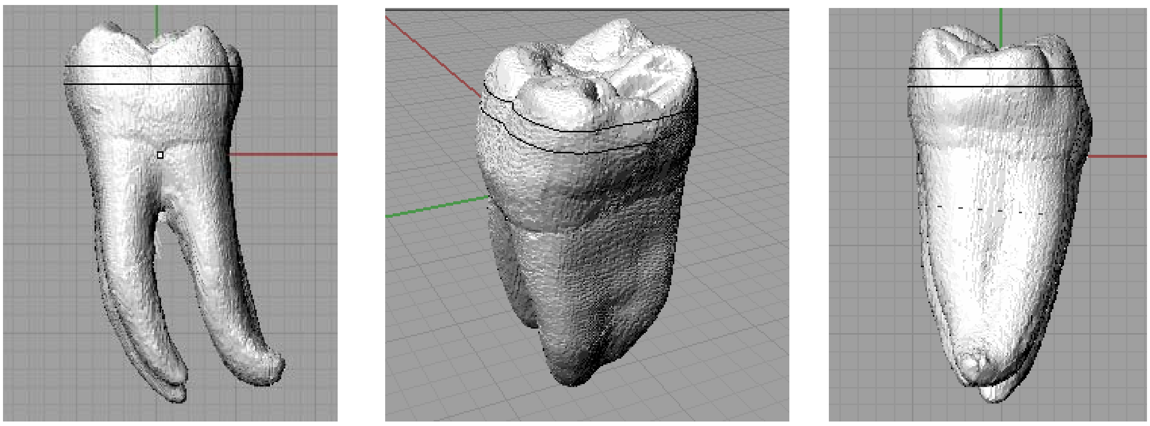


Fig.3. In the lower M1 section 5 and section 6 are provided. It is clear that section 6 drops above the base of the occlusal surface.

8.2 THE SECTIONS

From the five sections thus identified it is possible to obtain, for each of these, the profile length, the area and the second moments and make more precise repartition to evaluate specific aspects of tooth morphology. The starting point is the premise that the reference section is the first one, the one identified starting from middle cervical lingual point for the lower M1 and from the middle cervical buccal point for the upper M1. The section allows to get the profile of the cut part of the tooth, a profile which is essentially nothing more than a curve. To obtain the area rounded by this profile it is necessary to use the command “Surface from planar curves” (figure 4).

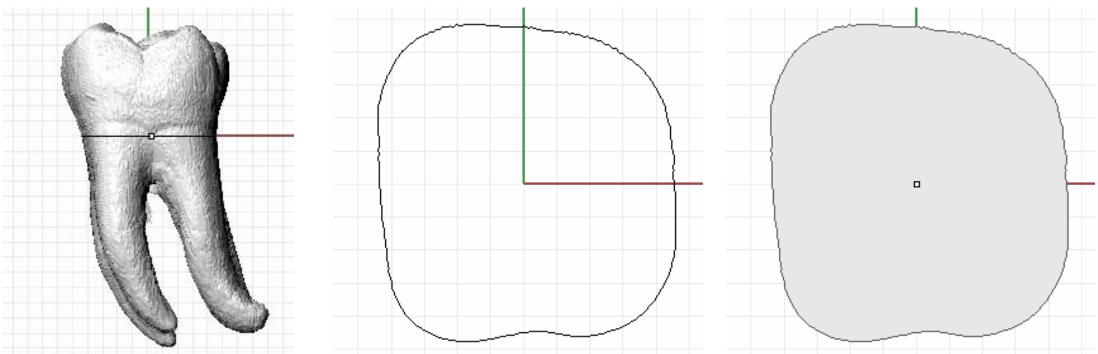


Fig.4. First section of a lower M1 (left), profile (middle) and surface of the section with its centroid (right)

We determine the centroid of the first section, its geometric centre, and from this we build two orthogonal planes, parallel to axis of Reference Cartesian System, which cut in four parts all five sections (figure 5).

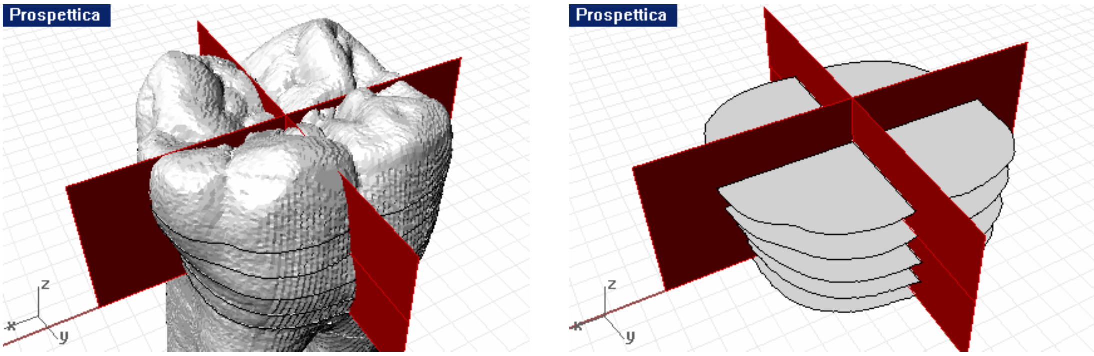


Fig.5. Lower M1 cut by two orthogonal planes passing to the centroid of the first section

Using the centroid of the first section we have a valuable system of reference to evaluate and quantify what are the morphological modifications of crown as from the cervical line it goes up to the cusps apexes. In case that the centroid of single sections coincides with that of first section we can infer that, apart from the dimensional difference that exists between the sections themselves, the tooth enlargement normally happens in an homogenous way along the four sides. In practice however this condition is hardly achievable, so we attend to a shift of the centroids of single sections.

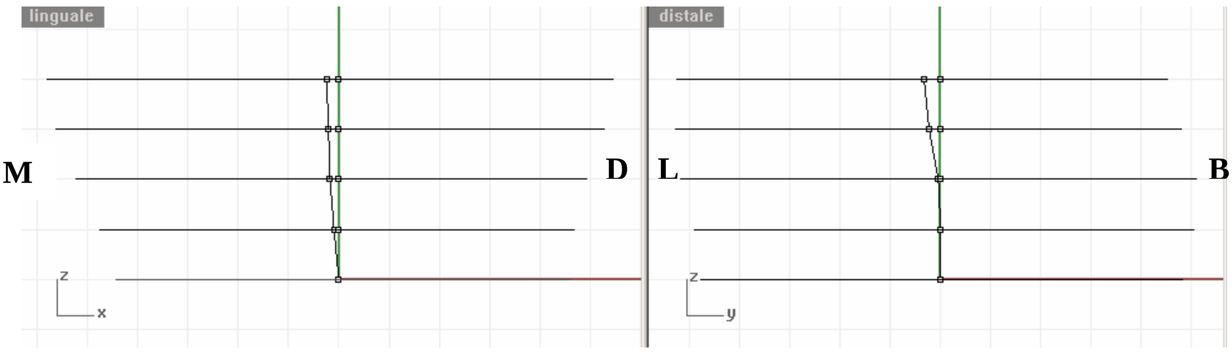


Fig. 6. Suppose to look at a right lower M1 from the lingual side (left) and distal side (right)

In figure 6, relative to lingual and distal view of five sections of a right lower M1 is highlighted the divergence between the centroid of the first section (copied in the following ones, which seem aligned along Y axis) and the centroid calculated in single sections. In this way it is easily guessed that, from a common base point (the centroid of the first section) the tooth morphology has different trends as it moves away from the cervical line.

In the specific case of figure 6, if we observe the tooth from lingual side (left picture) since centroids tend to move mesially it is clear that mesial part grows more than distal one. In the same way, if we observe the tooth from the distal side (right picture), if for the first two millimetres the tooth regularly grows in both parts (lingual and buccal), starting from the third section the lingual component of the crown increases more. Thereby, if we want to quantify or at least evaluate these differences it is necessary to maintain the centroid of the first section as a point of reference for all sections. If infact these variations can be minimum and probably not significant for a better comprehension of the teeth of Modern Human, they could instead provide useful information for studying fossil hominid species. However the sample used here appears to be too scanty to be able to formulate definitive considerations: it is necessary infact to have a more numerous sample to quantify the variability of single species and verify if this kind of approach, certainly invalidated in some way by a series of errors which firstly depend on the extreme morphologic variability of every single tooth, is nevertheless able to give back significant information.

8.3 DETERMINATION OF VARIABLES

For each section the variables obtained are as follows:

4. Profile length (Length S);
5. Area (A);
6. BL diameter and MD diameter, identified by a limit parallelepiped within is contained the section itself (figure 7). The limit parallelepiped is an useful tool to recognize the extreme points of the section in relation to the Reference Cartesian Plane, since the sides of parallelepiped are parallel to the axis of this plane.

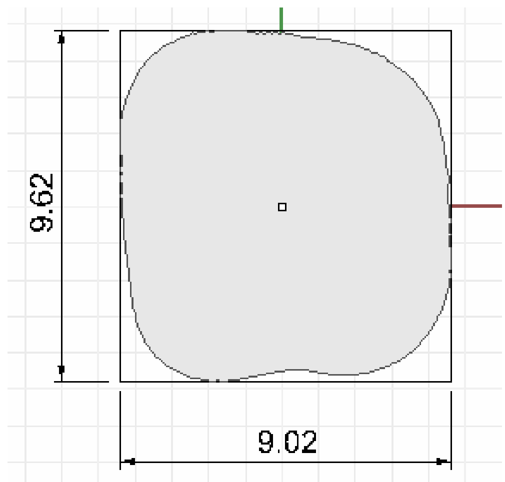


Fig. 7. BL and MD diameters

7. The second moments of the area: sometimes defined moment of inertia, indicated with capital letter “I”, is a term used to describe the propriety of a flat surface (such as a section) to resist to forces which tend to bend it. In the specific it analyzes the distribution of a surface area in relation to reference axis, as for example “x” and “y” axis of a Cartesian Reference System.

$$I_x = \int y^2 \, dA \qquad I_y = \int x^2 \, dA$$

y = distance from x axis to an infinitesimal area dA;

x = distance from y axis to an infinitesimal area dA;

High values of I indicate a higher resistance of the object to bend and to curve in a determined direction. The second moment has been calculated using “x” and “y” axis passing by the centroid[3] of each section, so obtaining data that can therefore be compared among sections of different teeth.

From these dimensional variables other variables which account for the tooth shape are obtained:

3. TS (taper): you get it from the ratio between two sections areas of the same tooth, reporting to the denominator the one which is closer to the cervical line. So usually the result is higher than 1, with the exception of the case where section 5 to numerator and section 4 to denominator, since the area of section 4 is often bigger. Through this variable it is possible to value the tooth “taper”: if we consider for instance section 5 and section 1 we notice that high results indicate a higher flare of the tooth than the case where the value is close to unity.
4. BL/MD: for each section the relation between BL diameter and MD one, in order to value if the tooth has grown more in bucco-lingual direction, or instead in mesio-distal one.
5. Ratio between second moments (Ix/Iy) of a section.

8.4 DIVIDE THE SECTIONS

Sections have been divided in four parts which have been named in the following way: mesio-buccal quadrant (A), disto-buccal quadrant (B), disto-lingual quadrant (C) and finally mesio-lingual one (D) (figure 8).

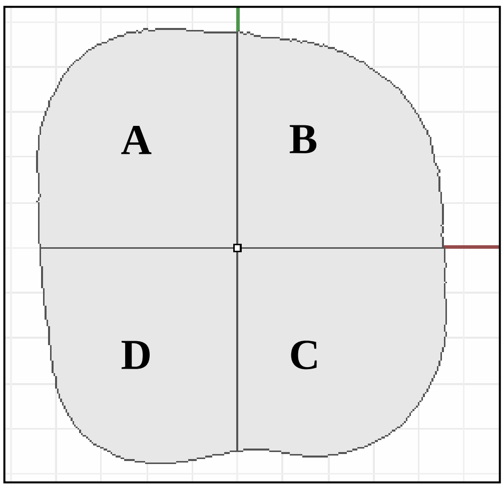


Fig. 8. Section divided in 4 quadrants

In this way it is possible to define a buccal component given by the addition of the two quadrants on buccal side (A+B), a distal component relative to the two quadrants on distal side (B+C) and so on for the other two faces of the tooth, the lingual (C+D) and the distal

[3] The centroid of a bidimensional surface (as the section of the surface can be) is a point which corresponds to the gravity centre of a flat object having a shape and area equal to that of surface.

(D+A). Supposing that the single quadrants can be more subject to a series of errors of different nature, using the sum of these to define the buccal, lingual, mesial and distal components respectively (defined on the base of the centroid) the importance of the error could be reduced.
As an example, in table 1 the variables gathered from the first section of a lower M1 are provided.

SAMPLE	SECTION 1									
	Length S1	A1	Quadrant area				Second moment		BL	MD
			A	B	C	D	Ix	Iy		
34_right_lower_M1	32,07	75,32	19,57	18,06	19,17	18,52	483,11	433,80	9,62	9,02

Table 1

At the end of this thesis all tables with the data obtained from the 5 sections of molars used in the present research, relative to dental samples representative of actual humanity (medieval period), Neanderthal and Modern Human (this last one from Upper Paleolithic), are reported.

8.5 STATISTIC ANALYSIS

In the following chapter the results of the statistic analysis made for lower M1 and upper M1 are provided, considering in a first phase the complete sections and afterwards using quadrants on the base of indications we referred to above. The analysis phases are anyway the same for both lower and upper M1. Samples have been divided in two groups: in the first have been included modern man's teeth (medieval period, so actual humanity, and Upper Paleolithic); group 2 represents the neanderthalian sample (including the tooth of Taddeo ceve and Poggio Cave).
Firstly a variance analysis (ANOVA) is carried out to observe if the average of each variable significantly differs in the two groups. Then is reported an analysis of main components, thus reducing the number of variables to few components not correlated and later, through a discriminant analysis, are determined the variables which provide the greater contribute to classify properly each cases in the respective groups. More in detail, specific discriminant functions are determined when are available 4 milliletres of dental crown (5 sections), 3 millimetres (4 sections), 2 milllimetres (3 sections), one millimetre (2 sections), and in the most reductive case, it is to say when the dental crown is completely destroyed but the cervical line trend (1 section) it's recognizable.

CHAPTER 9

9.1 RISULT: LOWER M1

Concerning the strong correlation among the second moments and the other size variables, from which no longer would an advantage be obtained using them, only the Ix/Iy ratio has been used about the second moments. In table 1 the results of the analysis of variance (ANOVA) regarding size variables (length, area and diameters) are provided. In all cases the p value is very low, and we can presume a good contribution of these variables for the classification of the groups.

ANOVA

Variable		Sum of Squares	df	Mean Square	F	Sig.
Length_S1	Between Groups	45,878	1	45,878	12,659	0,002
	Within Groups	83,355	23	3,624		
Length_S2	Between Groups	43,866	1	43,866	13,620	0,001
	Within Groups	74,075	23	3,221		
Length_S3	Between Groups	55,397	1	55,397	19,031	0,000
	Within Groups	64,039	22	2,911		
Length_S4	Between Groups	65,987	1	65,987	20,201	0,000
	Within Groups	71,865	22	3,267		
Length_S5	Between Groups	82,397	1	82,397	21,255	0,000
	Within Groups	81,407	21	3,877		
A1	Between Groups	1315,132	1	1315,132	14,030	0,001
	Within Groups	2155,891	23	93,734		
A2	Between Groups	1457,428	1	1457,428	15,698	0,001
	Within Groups	2135,401	23	92,844		
A3	Between Groups	1901,610	1	1901,610	21,593	0,000
	Within Groups	1937,496	22	88,068		
A4	Between Groups	2493,496	1	2493,496	24,820	0,000
	Within Groups	2210,227	22	100,465		
A5	Between Groups	2796,570	1	2796,570	22,294	0,000
	Within Groups	2634,227	21	125,439		
BL1	Between Groups	4,382	1	4,382	17,691	0,000
	Within Groups	5,697	23	0,248		
MD1	Between Groups	4,394	1	4,394	10,714	0,003
	Within Groups	9,433	23	0,410		
BL2	Between Groups	3,274	1	3,274	12,302	0,002
	Within Groups	6,122	23	0,266		
MD2	Between Groups	4,191	1	4,191	9,193	0,006
	Within Groups	10,485	23	0,456		
BL3	Between Groups	3,638	1	3,638	13,774	0,001
	Within Groups	6,075	23	0,264		
MD3	Between Groups	4,868	1	4,868	11,682	0,002
	Within Groups	9,584	23	0,417		
BL4	Between Groups	7,088	1	7,088	25,622	0,000
	Within Groups	6,086	22	0,277		
MD4	Between Groups	6,241	1	6,241	15,166	0,001
	Within Groups	9,054	22	0,412		
BL5	Between Groups	9,384	1	9,384	26,146	0,000
	Within Groups	7,537	21	0,359		
MD5	Between Groups	6,382	1	6,382	15,121	0,001
	Within Groups	8,863	21	0,422		

Table 1

The results of the analysis of variance for the shape variables are not significant, except the BL5/MD5 ratio (table 2). We can suppose a poor contribution of the shape variables for the discrimination of the cases in the correct group.

ANOVA						
Variable		Sum of Squares	df	Mean Square	F	Sig.
TS_5/1	Between Groups	0,004	1	0,004	0,805	0,380
	Within Groups	0,112	21	0,005		
TS_2/1	Between Groups	0,001	1	0,001	0,569	0,458
	Within Groups	0,022	23	0,001		
TS_3/1	Between Groups	0,002	1	0,002	0,540	0,470
	Within Groups	0,064	22	0,003		
TS_4/1	Between Groups	0,000	1	0,000	0,099	0,757
	Within Groups	0,083	22	0,004		
TS_4/2	Between Groups	0,001	1	0,001	0,431	0,518
	Within Groups	0,038	22	0,002		
TS_5/3	Between Groups	0,007	1	0,007	2,491	0,129
	Within Groups	0,060	21	0,003		
TS_5/4	Between Groups	0,001	1	0,001	1,402	0,250
	Within Groups	0,022	21	0,001		
TS_5/2	Between Groups	0,005	1	0,005	1,423	0,246
	Within Groups	0,079	21	0,004		
TS_4/3	Between Groups	0,002	1	0,002	3,829	0,063
	Within Groups	0,013	22	0,001		
BL1/MD1	Between Groups	0,000	1	0,000	0,008	0,931
	Within Groups	0,039	23	0,002		
BL2/MD2	Between Groups	0,002	1	0,002	0,922	0,347
	Within Groups	0,042	23	0,002		
BL3/MD3	Between Groups	0,000	1	0,000	0,228	0,638
	Within Groups	0,037	23	0,002		
BL4/MD4	Between Groups	0,001	1	0,001	0,431	0,518
	Within Groups	0,033	22	0,002		
BL5/MD5	Between Groups	0,004	1	0,004	5,010	0,036
	Within Groups	0,017	21	0,001		
Ix/Iy_S1	Between Groups	0,001	1	0,001	0,227	0,638
	Within Groups	0,104	23	0,005		
Ix/Iy_S2	Between Groups	0,014	1	0,014	2,759	0,110
	Within Groups	0,114	23	0,005		
Ix/Iy_S3	Between Groups	0,002	1	0,002	0,338	0,567
	Within Groups	0,105	22	0,005		
Ix/Iy_S4	Between Groups	0,003	1	0,003	0,620	0,440
	Within Groups	0,098	22	0,004		
Ix/Iy_S5	Between Groups	0,020	1	0,020	7,269	0,014
	Within Groups	0,057	21	0,003		

Table 2

A principle component analysis has been carried out for identifying a small number of uncorrelated factors that explain most of the variance observed in the manifest variables. All the size and shape variables have been entered (respectively 20 size variables and 19 shape variables) and 4 factors have been extracted (table 3).

Total Variance Explained						
	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	20,462	52,465	52,465	20,462	52,465	52,465
2	8,620	22,103	74,568	8,620	22,103	74,568
3	5,306	13,605	88,173	5,306	13,605	88,173
4	3,019	7,741	95,914	3,019	7,741	95,914

Table 3

As we can argue from the ANOVA results, the first component with maximum variance is defined by size variables, all strongly correlated together. Successive components explain progressively smaller portions of the variance and are all associated to the shape variables.

The second component is most highly correlated with the ratio of the diameters and the ratio of the second moments, while the other two factors are related to the taper of the sections (table 4).

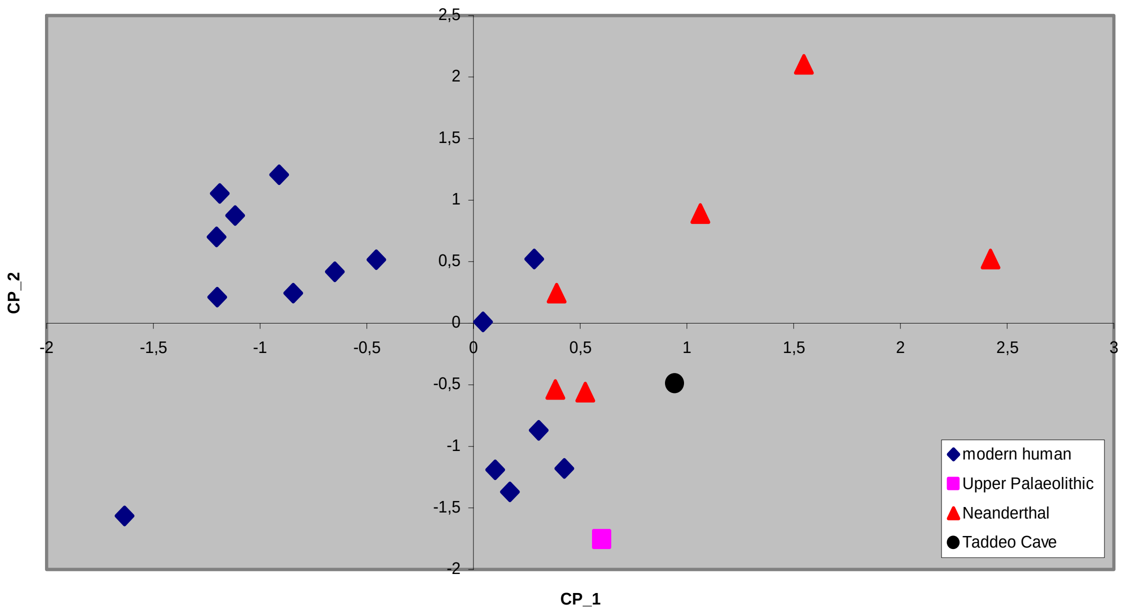
Component Matrix(a)

	Component					Component			
Variable	1	2	3	4	Variable	1	2	3	4
Length_S5	0,990	0,027	0,094	0,013	Ix/Iy_S4	0,006	0,952	-0,068	0,138
Length_S4	0,989	0,030	-0,023	0,091	BL4/MD4	-0,024	0,944	-0,133	0,081
A4	0,984	0,125	0,001	0,106	BL3/MD3	-0,294	0,935	-0,102	-0,040
A5	0,981	0,130	0,117	-0,031	Ix/Iy_S3	-0,320	0,920	-0,086	-0,047
A3	0,971	0,073	-0,134	0,168	Ix/Iy_S5	0,330	0,901	0,043	0,087
Length_S3	0,970	0,031	-0,135	0,173	BL5/MD5	0,320	0,882	0,000	0,012
A2	0,965	0,087	-0,223	0,065	BL2/MD2	-0,476	0,838	-0,118	-0,025
MD1	0,965	-0,164	-0,173	-0,069	BL1/MD1	-0,463	0,792	-0,134	0,002
A1	0,955	0,089	-0,251	-0,108	Ix/Iy_S2	-0,556	0,780	-0,114	-0,072
Length_S2	0,955	0,075	-0,241	0,078	Ix/Iy_S1	-0,501	0,705	-0,134	0,030
MD5	0,954	-0,161	0,182	0,010	TS_5/1	0,170	0,137	0,953	0,169
MD2	0,953	-0,224	-0,148	0,106	TS_4/2	0,196	0,195	0,889	0,154
BL5	0,953	0,260	0,130	0,023	TS_5/2	0,372	0,161	0,869	-0,264
Length_S1	0,952	0,084	-0,237	-0,098	TS_4/1	-0,055	0,124	0,768	0,621
MD4	0,938	-0,242	0,090	0,115	TS_4/3	0,443	0,356	0,726	-0,328
MD3	0,929	-0,276	-0,051	0,188	TS_5/3	0,453	0,209	0,692	-0,502
BL4	0,929	0,325	-0,024	0,161	TS_2/1	-0,344	-0,019	0,166	0,866
BL1	0,890	0,294	-0,295	-0,065	TS_3/1	-0,313	-0,037	0,407	0,854
BL3	0,890	0,346	-0,165	0,201	TS_5/4	0,424	0,097	0,601	-0,606
BL2	0,876	0,336	-0,290	0,121					

Extraction Method: Principal Component Analysis.
a 4 components extracted.

Table 4

Plotting the first 2 components against each other (in a simple scatterplot), the 2 groups (Modern Human and Neanderthal) are well separated with a very small overlap area (graphic 1). The molar of Taddeo Cave is clearly outside the border of Modern Human sample and it is well placed inside the Neanderthal group. Near the area of overlapping Neanderthal molars are Krapina 81, Petit Puy 3 and Devils Tower.



Graphic 1. Analysis of the principle components (5 sections)

From graphic 1 is clear that the best separation is provided by the first component that moves the Neanderthal group on the right of the graphic. It is also worthy to notice the position of the Upper Palaeolithic Human sample near the overlapping area, even if a sample may not be significant.

As we have seen, a good discrimination between the two major groups can be obtained by means of size variables. Nevertheless these variables are strongly correlated, and a choice is necessary. For this reason discriminant analysis is carried out in order to define the best size variable of the five sections. After that, the same procedure is used for determining the best shape variable. Finally we can obtain a new discriminant function for correct classification of the single cases based on a small number of size and shape variables.

9.2 DISCRIMINANT ANALYSIS: SIZE VARIABLES OF THE 5 SECTIONS

A Wilks' lambda stepwise method is used for entering the size variables. It is a variable selection method for stepwise discriminant analysis that chooses variables for entry into the equation on the basis of how much they lower Wilks' lambda. At each step, the variable that minimizes the overall Wilks' lambda is entered. The F value is used as a criterion for entering and removing variables. A variable is entered into the model if its F value is greater than the Entry value (3,84) and is removed if the F value is less than the Removal value (2,71).

Through the stepwise method the BL5 diameter is entered (table 5).

Variables Entered/Removed

			Wilks' Lambda							
							Exact F			
Step	Entered	Removed	Statistic	df1	df2	df3	Statistic	df1	df2	Sig.
1	BL5		0,445	1	1	21	26,146	1	21	0,000

Table 5

Using only the BL5 diameter 95,7% of original cases are correctly classified. Continuing, it is interesting to observe the Structure Matrix in table 6, in which the correlation of each predictor variable with the discriminant function is provided: higher values mean a stronger correlation with the discriminant function.

Structure Matrix			
	Function 1		
BL5	1	MD5(a)	0,816
A5(a)	0,964	A1(a)	0,803
BL4(a)	0,935	Length_S1(a)	0,801
A4(a)	0,933	Length_S2(a)	0,798
Length_S5(a)	0,918	BL2(a)	0,789
Length_S4(a)	0,890	BL1(a)	0,776
A3(a)	0,853	MD1(a)	0,759
BL3(a)	0,841	MD4(a)	0,728
Length_S3(a)	0,832	MD2(a)	0,702
A2(a)	0,825	MD3(a)	0,676

a This variable not used in the analysis.

Table 6

Drawing attention to the sequence of the variables, its clear a gradual decrease from the size variables of the five sections to the size variables of the first one exists. In particular, considering the first two variables for each section the condition shown in table 7 is achieved.

	SECTION				
N	S5	S4	S3	S2	S1
1	BL5				
2	A5				
3		BL4			
4		A4			
5			A3		
6			BL3		
7				A2	
8					A1
9					Length_S1
10				Length_S2	

Table 7. First 2 variables of each section in relation to their sequence in the Structure matrix are provided

For this reason we can argue that correct discrimination of original cases could improve using size variables of the more distant section from the cervical line. Nevertheless, considering that variables are strongly correlated with each other, there is not so many differences between them. In any case, we can observe that the selected two variables are almost the same for each section: always the area (A) and often the BL diameter.

It is necessary to define a new function using the size variable obtained before with some shape variables. In table 8 the result of the discriminant analysis for shape variables by means of stepwise method is provided.

Variables Entered/Removed										
			Wilks' Lambda							
							Exact F			
Step	Entered	Removed	Statistic	df1	df2	df3	Statistic	df1	df2	Sig.
1	Ix/Iy_S5		0,743	1	1	21	7,269	1	21	0,014
2	Ix/Iy_S3		0,283	2	1	21	25,332	2	20	0,000
3	BL1/MD1		0,195	3	1	21	26,086	3	19	0,000
4	Ix/Iy_S2		0,147	4	1	21	26,086	4	18	0,000

Table 8

Four variables are entered, and none of them are removed. Many discriminant analyses have been carried out using the entered shape variables and the BL5 diameter in different combinations. The best result is obtained using a combination of 3 variables:

1. a size variable (BL5);
2. two shape variables: BL1/MD1 and Ix2/Iy2;

In table 9 mean values, standard deviations of the variables introduced in the analysis and number of valid cases utilized, appropriately separated in the 2 groups (Modern Human and Neanderthal), are provided.

Group Statistics

Group	Variable	Mean	S.D.	Valid N (listwise) Unweighted	Weighted
1	BL5	10,18	0,56	16	16
	BL1/MD1	1,02	0,04	16	16
	Ix/Iy_S2	1,02	0,08	16	16
2	BL5	11,57	0,69	7	7
	BL1/MD1	1,01	0,04	7	7
	Ix/Iy_S2	0,97	0,06	7	7
Total	BL5	10,60	0,88	23	23
	BL1/MD1	1,02	0,04	23	23
	Ix/Iy_S2	1,00	0,08	23	23

Table 9

Entering these independent variables together (without a stepwise method), only one discriminant function has been identified. The fairly high eigenvalue, the rather high canonical correlation and the low value of the Wilks'Lambda indicate a great discriminatory capacity of the function, and the small significance value of the associated chi-square indicates that the discriminant function does better versus the chance at separating the groups (table 10).

Canonical discriminant function

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation	Wilks' Lambda	Chi-square	df	Sig.
1	3,114	100	100	0,870	0,243	27,581	3	0,000

Table 10

Classification Function Coefficients

	Group 1	2
BL5	69,19	75,29
BL1/MD1	3207,46	3412,99
Ix/Iy_S2	-1442,59	-1555,20
(Constant)	-1250,32	-1413,60

Fisher's linear discriminant functions

Table 11

By means of Fisher's linear discriminant functions (table 11), where a case is assigned to the group for which it has the largest discriminant score, 100% of the original cases are correctly classified. This result doesn't change with a cross-validation method (table 12). Cross validation divides the sample into a number of sub samples, or folds. Tree models are then generated, excluding the data from each sub sample in turn. The first tree is based on all of the cases except those in the first sample fold; the second tree is based on all of the cases except those in the second sample fold and so on. For each tree, misclassification risk is estimated by applying the tree to the sub sample excluded in generating it. Cross validation produces a single, final tree model. The cross validated risk estimate for the final tree is calculated as the average of the risks for all of the trees

Classification Results

		Group	Predicted Group Membership 1	2	Total
Original	Count	1	16	0	16
		2	0	7	7
	%	1	100	0	100
		2	0	100	100
Cross-validated	Count	1	16	0	16
		2	0	7	7
	%	1	100	0	100
		2	0	100	100

100% of original grouped cases correctly classified.

100% of cross-validated grouped cases correctly classified.

Table 12

In this research, one needs to make use of 5 sections corresponding to the best condition, where doing this means that 4 millimetres of the crown are preserved. Nevertheless, I have already underlined that in paleoanthropological field human dental remains are usually worn, and it is frequent to discover crown height less than 4 millimetres. For this reason other discriminant analyses have been carried out supposing different wear conditions of the teeth. So, depending on the degree of wear of the tooth under investigation, it will be possible to choose the right variables.

9.2.1 DISCRIMINANT ANALYSIS: 4 SECTIONS

In this case only 3 millimetres of the crown are preserved. In table 13, group statistics based on the three variables used in this analysis are shown. The size variable has been selected in relation to the order provided in table 7 (BL4), while the shape variables remain the same as used before. The three variables have been entered in the discriminant analysis without stepwise method.

Group Statistics					
				Valid N (listwise)	
Group	Variable	Mean	S.D.	Unweighted	Weighted
1	BL4	10,58	0,45	17	17
	BL1/MD1	1,02	0,04	17	17
	Ix/Iy_S2	1,02	0,08	17	17
2	BL4	11,78	0,69	7	7
	BL1/MD1	1,01	0,04	7	7
	Ix/Iy_S2	0,97	0,06	7	7
Total	BL4	10,93	0,76	24	24
	BL1/MD1	1,01	0,04	24	24
	Ix/Iy_S2	1,00	0,07	24	24

Table 13

As we could presume, the values shown in the Canonical discriminant function table (table 14), are very similar to those obtained using BL5 instead than BL4.

Canonical discriminant function								
Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation	Wilks' Lambda	Chi-square	df	Sig.
1	3,008	100	100	0,870	0,250	28,459	3	0,000

Table 14

Classification Function Coefficients		
	Gruppo	
	1	2
BL4	76,18	82,86
BL1/MD1	2970,66	3168,52
Ix/Iy_S2	-1394,92	-1509,97
(Constant)	-1202,90	-1364,22

Fisher's linear discriminant functions

Table 15

With Fisher's linear discriminant functions (table 15), 100% of original cases are correctly classified. This result doesn't change with a cross-validation method (table 16).

Classification Results					
			Predicted Group Membership		
		Group	1	2	Total
Original	Count	1	17	0	17
		2	0	7	7
	%	1	100	0	100
		2	0	100	100
Cross-validated	Count	1	17	0	17
		2	0	7	7
	%	1	100,00	0	100
		2	0	100	100

100% of original grouped cases correctly classified.

100% of cross-validated grouped cases correctly classified.

Table 16

9.2.2 DISCRIMINANT ANALYSIS: 3 SECTIONS

In this case only 2 millimetres of the crown are preserved. In table 17 group statistics based on the three variables used in this analysis are shown. As mentioned above in regard on table 7, A3 is the size variable used in this analysis while the shape variables remains the same (BL1/MD1 and Ix2/Iy2).

Group Statistics

Group	Variable	Mean	S.D.	Valid N (listwise) Unweighted	Valid N (listwise) Weighted
1	A3	99,16	8,40	17	17
	BL1/MD1	1,02	0,04	17	17
	Ix/Iy_S2	1,02	0,08	17	17
2	A3	118,75	11,60	7	7
	BL1/MD1	1,01	0,04	7	7
	Ix/Iy_S2	0,97	0,06	7	7
Total	A3	104,88	12,92	24	24
	BL1/MD1	1,01	0,04	24	24
	Ix/Iy_S2	1,00	0,07	24	24

Table 17

The values shown in table 18, even if not as good as previous conditions, are still good. Canonical Correlation is fairly high while at the same time Wilks'Lambda has a fairly low value.

Canonical discriminant function

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation	Wilks' Lambda	Chi-square	df	Sig.
1	2,421	100	100	0,841	0,292	25,215	3	0,000

Table 18

Classification Function Coefficients

	Gruppo 1	Gruppo 2
A3	3,67	4,01
BL1_MD1	2667,57	2842,44
Ix_Iy_S2	-1086,86	-1176,04
(Constant)	-984,46	-1110,36

Fisher's linear discriminant functions

Table 19

With Fisher's linear discriminant functions (table 19), 100% of original cases are correctly classified, even if the result is slightly lower in a cross-validation analysis, in which 2 molars are misclassified (table 20). One of these is the Krapina 81 molar. It is worthy to notice that with 2 millimetres of crown preserved, the molar of Taddeo Cave is still considered inside the Neanderthal group.

Classification Results					
			Predicted Group Membership		
		Group	1	2	Total
Original	Count	1	17	0	17
		2	0	7	8
	%	1	100	0	100
		2	0	100	100
Cross-validated	Count	1	16	1	17
		2	1	6	8
	%	1	94,12	5,88	100
		2	14,29	85,71	100

100% of original grouped cases correctly classified.
91,7% of cross-validated grouped cases correctly classified.

Table 20

9.2.3 DISCRIMINANT ANALYSIS: 2 SECTIONS

In this case only 1 millimetre of the crown is preserved. In table 21 group statistics based on the three variables used in this analysis are shown. By means of a discriminant analysis with stepwise method carried out only for size variables, BL1 diameter has been selected. Also in this new condition the shape variables remain the same (BL1/MD1 and Ix2/Iy2).

Group Statistics					
				Valid N (listwise)	
Group	Variable	Mean	S.D.	Unweighted	Weighted
1	BL1	9,85	0,36	17	17
	BL1/MD1	1,02	0,04	17	17
	Ix/Iy_S2	1,02	0,08	17	17
2	BL1	10,75	0,72	8	8
	BL1/MD1	1,01	0,04	8	8
	Ix/Iy_S2	0,97	0,05	8	8
Total	BL1	10,14	0,65	25	25
	BL1/MD1	1,01	0,04	25	25
	Ix/Iy_S2	1,00	0,07	25	25

Table 21

Looking at the table 22, the results are very similar to those obtained with 2 millimetres of crown.

Canonical discriminant function								
Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation	Wilks' Lambda	Chi-square	df	Sig.
1	1,926	100	100	0,811	0,342	23,081	3	0,000

Table 22

Classification Function Coefficients		
	Gruppo	
	1	2
BL1	52,00	56,46
BL1/MD1	2300,85	2439,43
Ix/Iy_S2	-1062,67	-1149,37
(Constant)	-884,74	-985,30

Fisher's linear discriminant functions

Table 23

For this reason, it is not strange that with Fisher's linear discriminant functions (table 23), 100% of original cases are correctly classified, even if the result is slightly lower in a cross-validation analysis, in which 2 molars are misclassified (table 24). It is interesting to notice that all Neanderthal molars are correctly classified.

Classification Results

			Predicted Group Membership		
		Group	1	2	Total
Original	Count	1	17	0	17
		2	0	8	8
	%	1	100	0	100
		2	0	100	100
Cross-validated	Count	1	15	2	17
		2	0	8	8
	%	1	88,24	11,76	100
		2	0	100	100

100% of original grouped cases correctly classified.
92% of cross-validated grouped cases correctly classified.

Table 24

9.2.4 DISCRIMINANT ANALYSIS: 1 SECTION

In this condition the tooth is almost completely worn, but the presence of the cervical line gives us the possibility to create at least a section. For this reason it is possible to use only the variable of the first section. In table 25 group statistics of the 2 variable used in this analysis are provided (BL1 and BL1/MD1).

Group Statistics

				Valid N (listwise)	
Group	Variable	Mean	S.D.	Unweighted	Weighted
1	BL1	9,85	0,36	17	17
	BL1/MD1	1,02	0,04	17	17
2	BL1	10,75	0,72	8	8
	BL1/MD1	1,01	0,04	8	8
Total	BL1	10,14	0,65	25	25
	BL1/MD1	1,01	0,04	25	25

Table 25

Considering table 26, the low value of the Canonical Correlation and the fairly high value of the Wilks'Lambda denote that the new discriminant function is not as good as those previously obtained.

Canonical discriminant function

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation	Wilks' Lambda	Chi-square	df	Sig.
1	0,769	100	100	0,659	0,565	12,555	2	0,002

Table 26

Classification Function Coefficients		
	Gruppo	
	1	2
BL1	41,80	45,43
BL1/MD1	612,59	613,43
(Constant)	-517,55	-555,75

Fisher's linear discriminant functions

Table 27

In fact, with Fisher's linear discriminant functions (table 27) 88% of original cases are correctly classified, and this result is further reduced with a cross-validation analysis (table 28). The situation is relatively worse for the Neanderthal sample, because 2 cases are misclassified: Petit Puy 3 and Vindija 226. It's important to notice that also in this limited condition, the molar of Taddeo Cave is classified in the Neanderthal group.

Classification Results					
			Predicted Group Membership		
		Group	1	2	Total
Original	Count	1	16	1	17
		2	2	6	8
	%	1	94,1	5,9	100
		2	25,0	75,0	100
Cross-validated	Count	1	15	2	17
		2	2	6	8
	%	1	88,2	11,8	100
		2	25,0	75,0	100

88% of original grouped cases correctly classified.

84% of cross-validated grouped cases correctly classified.

Table 28

There are not so many differences in the final result if the BL1/MD1 variable is omitted from the analysis. With the new discriminant function, based only on BL1 diameter, 84% of original cases are correctly classified. This result doesn't change with a cross-validation method.

9.3 QUADRANTS

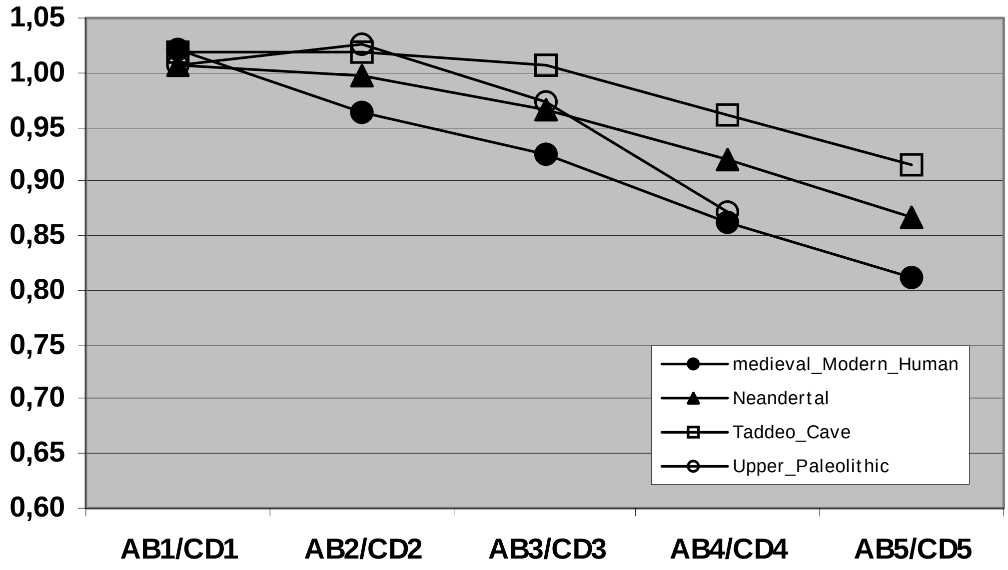
As mentioned in the previous chapter, each section is characterized by 2 variables: AB/CD and BC/DA, of which some descriptive statistics are shown in table 29.

DESCRIPTIVES						
					95% C.I. for Mean	
Variables	Group	N	Mean	S.D.	Lower Bound	Upper Bound
AB1/CD1	1	17	1,02	0,07	0,98	1,06
	2	8	1,01	0,01	1,00	1,02
BC1/DA1	1	17	0,97	0,06	0,93	1,00
	2	8	1,00	0,01	0,99	1,01
AB2/CD2	1	17	0,97	0,05	0,95	1,00
	2	8	1,00	0,02	0,99	1,02
BC2/DA2	1	17	0,95	0,03	0,93	0,96
	2	8	0,99	0,02	0,98	1,00
AB3/CD3	1	17	0,93	0,06	0,90	0,96
	2	7	0,97	0,05	0,92	1,02
BC3/DA3	1	17	0,92	0,05	0,90	0,94
	2	7	0,96	0,03	0,93	0,98
AB4/CD4	1	17	0,86	0,05	0,83	0,89
	2	7	0,93	0,07	0,86	0,99
BC4/DA4	1	17	0,91	0,05	0,88	0,93
	2	7	0,93	0,03	0,90	0,95
AB5/CD5	1	16	0,81	0,07	0,77	0,85
	2	7	0,87	0,09	0,79	0,95
BC5/DA5	1	16	0,91	0,05	0,89	0,94
	2	7	0,91	0,03	0,88	0,94

Table 29

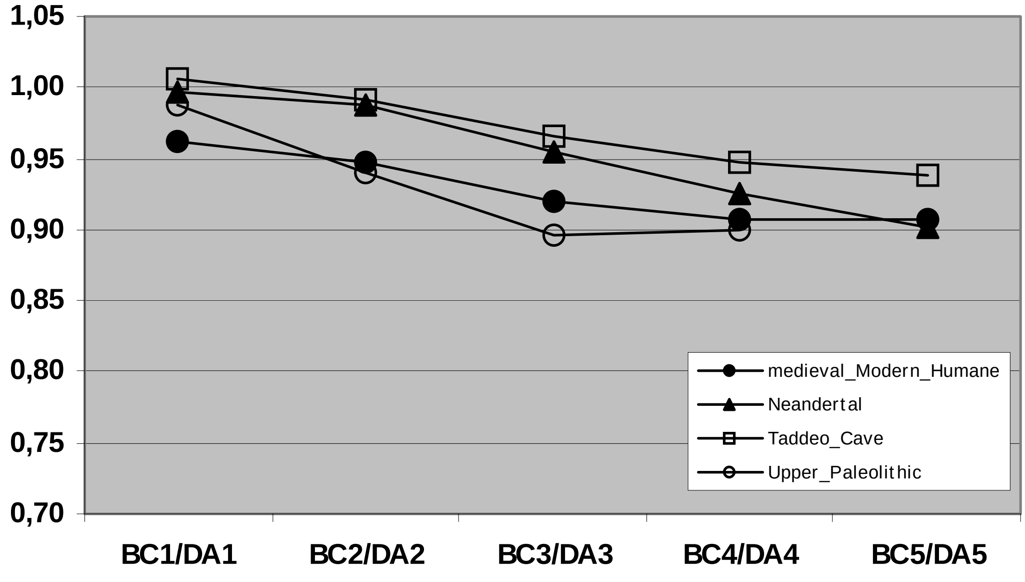
As we can understand from the means, Neanderthal samples usually have higher values than the Modern Human ones. Graphic 2 and 3 clearly indicate that the means of the two major groups gradually decrease from section 1 to section 5, but this trend is less marked in the Neanderthal samples. This means less of a difference in quadrant sizes in Neanderthal than Modern Human, for which instead the lower results indicate a relatively bigger dimension respectively for the lingual part as well as the mesial section of the crown.

Regarding the AB/CD ratio, it is also interesting to notice the trend of the molar of Taddeo Cave that is almost the same seen for the Neanderthal group, even if its means are greater. Nonetheless the analysis of variance between Neanderthal and Modern Human group is not significant, except for the section 4 (table 30).



Graphic 2. Bucco-lingual ratio (AB/CD)

This is different for the BC/DA ratio. The higher values obtained for the molar of Taddeo Cave are more similar to the Neaderthal group than the Modern Human one: in particular for the first three sections there is an almost overlapping of the two lines.



Graphic 3. Disto-mesial ratio (BC/DA)

The analysis of variance (table 30) provides a significant difference for BC/DA ratio in section 2 and 3 ($p \leq 0,05$), exactly where the molar of Taddeo Cave overlaps the Neanderthal Group. For this reason it would seem that the first 2 millimetres of the crown (starting from the cervical line), have a different development between Neanderthal and Modern Human at least for the BC/DA ratio.

Variable		Sum of Squares	df	Mean Square	F	Sig.
AB1/CD1	Between Groups	0,001	1	0,001	0,220	0,644
	Within Groups	0,080	23	0,003		
BC1/DA1	Between Groups	0,006	1	0,006	2,496	0,128
	Within Groups	0,056	23	0,002		
AB2/CD2	Between Groups	0,004	1	0,004	2,045	0,166
	Within Groups	0,049	23	0,002		
BC2/DA2	Between Groups	0,009	1	0,009	14,085	0,001
	Within Groups	0,015	23	0,001		
AB3/CD3	Between Groups	0,010	1	0,010	2,987	0,098
	Within Groups	0,075	22	0,003		
BC3/DA3	Between Groups	0,007	1	0,007	4,315	0,050
	Within Groups	0,037	22	0,002		
AB4/CD4	Between Groups	0,021	1	0,021	5,852	0,024
	Within Groups	0,078	22	0,004		
BC4/DA4	Between Groups	0,002	1	0,002	0,945	0,342
	Within Groups	0,042	22	0,002		
AB5/CD5	Between Groups	0,020	1	0,020	3,632	0,070
	Within Groups	0,116	21	0,006		
BC57DA5	Between Groups	0,000	1	0,000	0,046	0,831
	Within Groups	0,037	21	0,002		

Table 30

Anyway these considerations have to be supported by more investigations. It is interesting to notice here the different possibilities that the new three-dimensional approach can supply. In general, for the aims of this research, the new approach has allowed us to assign the molar of Taddeo Cave inside the Neanderthal group.

CHAPTER 10

10.1 RESULT: UPPER M1

In regard to the wear of the upper first molar of Taddeo Cave, of which less than 4 mm of crown is preserved, only 4 sections were possible, the first ones passing to the middle point on the buccal cervical line and parallel to the Reference Cartesian Plane.

10.2 ANALYSIS OF THE PRINCIPLE COMPONENTS

The results of the analysis of variance (ANOVA) are significantly different between the groups. In particular, all the dimensional variables are strongly correlated to each other and the p value is always less than 0,00 (table 1). Also for some shape variables (BL/MD ratio and Ix/Iy ratio) the p value is significantly different between the groups (table 2)

ANOVA

Variable		Sum of Squares	df	Mean Square	F	Sig.
Length_S1	Between Groups	104,902	1	104,902	31,868	0,000
	Within Groups	75,710	23	3,292		
Length_S2	Between Groups	105,658	1	105,658	27,116	0,000
	Within Groups	81,827	21	3,897		
Length_S3	Between Groups	111,915	1	111,915	22,851	0,000
	Within Groups	102,850	21	4,898		
Length_S4	Between Groups	111,450	1	111,450	18,689	0,000
	Within Groups	137,159	23	5,963		
A1	Between Groups	2640,452	1	2640,452	35,478	0,000
	Within Groups	1711,792	23	74,426		
A2	Between Groups	2914,784	1	2914,784	33,910	0,000
	Within Groups	1805,061	21	85,955		
A3	Between Groups	3033,099	1	3033,099	26,187	0,000
	Within Groups	2432,279	21	115,823		
A4	Between Groups	2835,030	1	2835,030	16,774	0,000
	Within Groups	3887,245	23	169,011		
BL1	Between Groups	4,752	1	4,752	12,885	0,002
	Within Groups	8,482	23	0,369		
MD1	Between Groups	17,996	1	17,996	73,949	0,000
	Within Groups	5,597	23	0,243		
BL2	Between Groups	4,385	1	4,385	12,311	0,002
	Within Groups	7,835	22	0,356		
MD2	Between Groups	18,732	1	18,732	68,409	0,000
	Within Groups	6,024	22	0,274		
BL3	Between Groups	4,462	1	4,462	10,799	0,003
	Within Groups	9,090	22	0,413		
MD3	Between Groups	17,420	1	17,420	51,565	0,000
	Within Groups	7,432	22	0,338		
BL4	Between Groups	5,512	1	5,512	10,201	0,004
	Within Groups	12,426	23	0,540		
MD4	Between Groups	14,619	1	14,619	29,302	0,000
	Within Groups	11,475	23	0,499		

Table 1

ANOVA						
Variable		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
TS_2/1	Between Groups	0,000	1	0,000	0,191	0,666
	Within Groups	0,017	21	0,001		
TS_3/1	Between Groups	0,002	1	0,002	0,636	0,434
	Within Groups	0,074	21	0,004		
TS_4/1	Between Groups	0,013	1	0,013	1,811	0,191
	Within Groups	0,167	23	0,007		
TS_4/2	Between Groups	0,005	1	0,005	1,686	0,208
	Within Groups	0,066	21	0,003		
TS_4/3	Between Groups	0,002	1	0,002	2,440	0,133
	Within Groups	0,015	21	0,001		
BL1/MD1	Between Groups	0,097	1	0,097	43,851	0,000
	Within Groups	0,051	23	0,002		
BL2/MD2	Between Groups	0,075	1	0,075	39,511	0,000
	Within Groups	0,042	22	0,002		
BL3/MD3	Between Groups	0,044	1	0,044	29,027	0,000
	Within Groups	0,033	22	0,002		
BL4/MD4	Between Groups	0,017	1	0,017	15,104	0,001
	Within Groups	0,025	23	0,001		
Ix/Iy_S1	Between Groups	0,462	1	0,462	36,928	0,000
	Within Groups	0,288	23	0,013		
Ix/Iy_S2	Between Groups	0,298	1	0,298	15,589	0,001
	Within Groups	0,420	22	0,019		
Ix/Iy_S3	Between Groups	0,169	1	0,169	24,371	0,000
	Within Groups	0,146	21	0,007		
Ix/Iy_S4	Between Groups	0,027	1	0,027	6,036	0,022
	Within Groups	0,097	22	0,004		

Table 2

As shown in table 3, in the Principle Component Analysis 3 components have been identified. These new uncorrelated linear components explain about the 95% of the variance observed in the lager number of manifest variables.

Total Variance Explained						
	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	17,459	60,203	60,203	17,459	60,203	60,203
2	5,361	18,485	78,688	5,361	18,485	78,688
3	4,583	15,802	94,490	4,583	15,802	94,490

Table 3

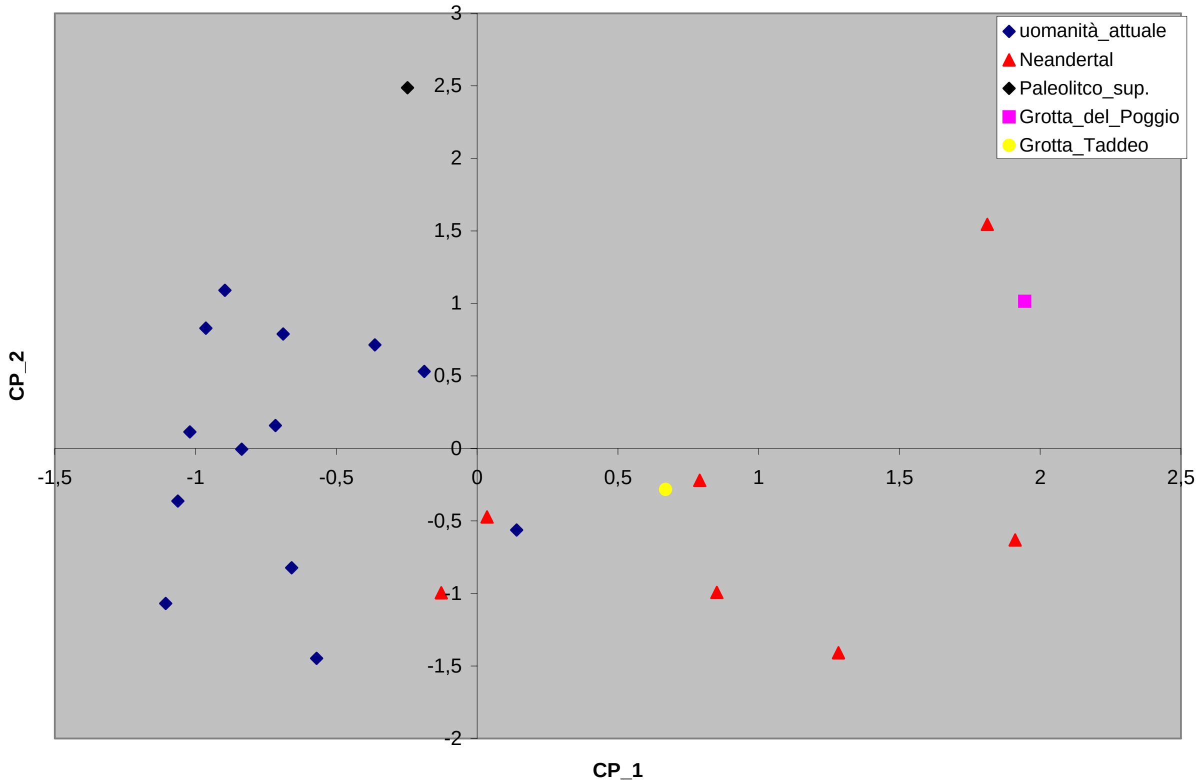
The first component is most highly correlated with dimensional variables, while the second component is most highly correlated with the ratio of the diameters and the ratio of the second moments (table 4).

Component Matrix(a)							
	Component				Component		
Variable	1	2	3	Variable	1	2	3
MD3	0,991	-0,074	0,069	BL1	0,801	0,538	-0,176
MD2	0,987	-0,040	-0,107	BL1/MD1	-0,765	0,529	0,190
A3	0,972	0,195	0,120	BL2/MD2	-0,764	0,593	0,126
MD1	0,968	0,002	-0,222	Ix/Iy_S2	-0,741	0,638	0,105
A2	0,967	0,233	-0,066	Ix/Iy_S1	-0,727	0,601	0,178
MD4	0,965	-0,004	0,229	BL4/MD4	-0,515	0,775	-0,003
Length_S3	0,962	0,219	0,123	Ix/Iy_S4	-0,391	0,749	0,020
Length_S2	0,957	0,261	-0,005	BL3/MD3	-0,676	0,716	0,033
Length_S4	0,942	0,219	0,218	Ix/Iy_S3	-0,680	0,712	0,052
Length_S1	0,938	0,309	-0,136	TS_4/1	0,031	-0,144	0,987
A4	0,934	0,222	0,273	TS_4/2	0,042	0,009	0,960
A1	0,934	0,298	-0,191	TS_3/1	-0,017	-0,305	0,913
BL4	0,869	0,416	0,258	TS_4/3	0,061	0,206	0,875
BL3	0,859	0,486	0,126	TS_2/1	-0,032	-0,365	0,736
BL2	0,824	0,543	-0,067				

Extraction Method: Principal Component Analysis.
a 3 components extracted.

Table 4

Plotting the first 2 components against each other (in simple scatterplots), the 2 groups (modern human and Neanderthal) are well separated with a small overlap area. The molar of Poggio Cave is at the external border of the Neandertal variability, while the molar of Taddeo Cave is inside the Neanderthal group (graphic 1).



Graphic 1. Analysis of the principle components (4 sections)

10.3 DISCRIMINANT ANALYSIS: 4 SECTIONS

In order to determine which variables provide the best discrimination between the groups when 3 millimetres of dental crown are preserved, a Discriminant Analysis is carried out.

By means of a stepwise analysis, 3 variables have been entered, one of which was subsequently removed (table 5).

Variables Entered/Removed

			Wilks' Lambda							
							Exact F			
Step	Entered	Removed	Statistic	df1	df2	df3	Statistic	df1	df2	Sig.
1	MD2		0,248	1	1	21	63,661	1	21	0,000
2	BL4		0,176	2	1	21	46,723	2	20	0,000
3	A3		0,142	3	1	21	38,137	3	19	0,000
4		MD2	0,149	2	1	21	57,277	2	20	0,000

Table 5

In table 6 subgroup means, standard deviation and number of cases are shown.

Group Statistics

				Valid N (listwise)	
Group	Variable	Mean	S.D.	Unweighted	Weighted
1	A3	102,27	7,38	14	14
	BL4	11,64	0,57	14	14
2	A3	125,80	14,68	9	9
	BL4	12,63	1,01	9	9
Total	A3	111,48	15,76	23	23
	BL4	12,03	0,90	23	23

Table 6

The high eigenvalue and the low value of the Wilks'Lambda indicate great discriminatory ability of the function, and the small significance value of the associated chi-square indicates that the discriminant function does better versus chance at separating the groups (table 7).

Canonical discriminant function

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation	Wilks' Lambda	Chi-square	df	Sig.
1	5,728	100	100	0,923	0,149	38,125	2	0,000

Table 7

Classification Function Coefficients

	Gruppo	
	1	2
A3	-12,19	-10,13
BL4	187,82	161,11
(Constant)	-470,30	-381,31

Fisher's linear discriminant functions

Table 8

With Fisher's linear discriminant functions (table 8), where a case is assigned to the group for which it has the largest discriminant score, 100% of original cases are correctly classified. This result doesn't change with a cross-validation method (table 9).

Classification Results

		Group	Predicted Group Membership 1	2	Total
Original	Count	1	14	0	14
		2	0	9	9
	%	1	100	0	100
		2	0	100	100
Cross-validated(a)	Count	1	14	0	14
		2	0	9	9
	%	1	100	0	100
		2	0	100	100

100% of original grouped cases correctly classified.

100% of cross-validated grouped cases correctly classified.

Table 9

10.3.1 DISCRIMINANT ANALYSIS: 3 SECTIONS

A discriminant analysis with a stepwise method has been carried out using dimensional and shape variables. Two dimensional variables are entered: MD2 and BL3 (table 10).

Variables Entered/Removed

			Wilks' Lambda							
							Exact F			
Step	Entered	Removed	Statistic	df1	df2	df3	Statistic	df1	df2	Sig.
1	MD2		0,248	1	1	21	63,661	1	21	0,000
2	BL3		0,200	2	1	21	40,063	2	20	0,000

Table 10

Of the cases used to create the model, 95.8% are classified correctly, even if the cross-validation method reduces this result (87.5%). For this reason a new discriminant function based on 3 variables has been determined: the two dimensional variables obtained with the stepwise method and the first shape variable reported in the structure matrix (table 11). In this matrix the position of each variable is based on their correlation with the canonical discriminant function.

Structure Matrix			
Function 1			
MD2	0,870	BL3/MD3(a)	-0,532
MD1(a)	0,825	Length_S2(a)	0,530
BL2/MD2(a)	-0,764	Ix/Iy_S3(a)	-0,517
MD3(a)	0,762	Length_S1(a)	0,503
BL1/MD1(a)	-0,755	A1(a)	0,498
Iy_S2(a)	0,695	Ix_S3(a)	0,449
Ix/Iy_S2(a)	-0,675	Ix_S2(a)	0,399
Iy_S1(a)	0,646	Ix_S1(a)	0,360
Ix_/Iy_S1(a)	-0,634	BL3	0,358
Iy_S3(a)	0,634	BL1(a)	0,279
A2(a)	0,563	BL2(a)	0,278
A3(a)	0,560	TS_3/1(a)	0,115
Length_S3(a)	0,549	TS_2/1(a)	0,093
a This variable not used in the analysis.			

Table 11

The ratio of the diameters of the second section has been chosen (BL2/MD2). In table 12 the subgroups means of the 3 variables are shown.

Group Statistics					
				Valid N (listwise)	
Group	Variable	Mean	S.D.	Unweighted	Weighted
1	MD2	9,76	0,40	15	15
	BL3	11,95	0,51	15	15
	BL2/MD2	1,22	0,04	15	15
2	MD2	11,58	0,68	9	9
	BL3	12,84	0,83	9	9
	BL2/MD2	1,10	0,04	9	9
Total	MD2	10,44	1,04	24	24
	BL3	12,29	0,77	24	24
	BL2/MD2	1,18	0,07	24	24

Table 12

The new discriminant function has a high eigenvalue and a low value of the Wilks'Lambda (table 13).

Canonical discriminant function								
Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation	Wilks' Lambda	Chi-square	df	Sig.
1	4,502	100	100	0,905	0,182	34,956	3	0,000

Table 13

With Fisher's linear discriminant functions based on 3 variables (table 14) the result is improved, because 100% of the original cases are correctly classified (24 cases), and in the cross-validation analysis only 2 cases are misclassified (table 15). In particular, for the second group only the Neanderthal teeth of La Quina 18 have been classified inside the first group. It's remarkable to notice that the molars of Taddeo Cave and Poggio Cave are classified in the Neanderthal group (second group).

Classification Function Coefficients		
	Gruppo	
	1	2
MD2	633,66	653,76
BL3	-450,74	-462,35
BL2/MD2	5237,44	5313,08
(Constant)	-3593,15	-3751,64

Fisher's linear discriminant functions

Table 14

Classification Results					
			Predicted Group Membership		
		Group	1	2	Total
Original	Count	1	15	0	15
		2	0	9	9
	%	1	100	0	100
		2	0	100	100
Cross-validated	Count	1	14	1	15
		2	1	8	9
	%	1	93,3	6,7	100
		2	11,1	88,9	100

100% of original grouped cases correctly classified.
91,7% of cross-validated grouped cases correctly classified.

Table 15

10.3.2 DISCRIMINANT ANALYSIS: 2 SECTIONS

If 1 millimetre of crown is preserved, it is possible to make only 2 sections. Through a discriminant analysis by means of a stepwise method, with all size and shape variables used, the MD2 diameter is entered. As you can see in table 16, the MD1 diameter is in the second position.

Structure Matrix			
Function 1			
MD2	1,000	BL1(a)	0,661
MD1(a)	0,950	BL1/MD1(a)	-0,412
A2(a)	0,887	BL2/MD2(a)	-0,400
Length_S2(a)	0,865	Ix/Iy_S2(a)	-0,324
Length_S1(a)	0,834	Ix/Iy_S1(a)	-0,281
A1(a)	0,818	TS_2/1(a)	0,044
BL2(a)	0,694		

a This variable not used in the analysis.

Table 16

At any rate this diameter provides a better result than the MD2 diameter, and is worthy to note that other size or shape variables used together with MD1 diameter do not improve the result. For this reason a discriminant functional analysis has been obtained using only the MD1 diameter (table 17).

Group Statistics

Group	Variable	Mean	S.D.	Valid N (listwise) Unweighted	Weighted
1	MD1	8,92	0,41	16	16
2	MD1	10,68	0,62	9	9
Total	MD1	9,55	0,99	25	25

Table 17

The fairly high eigenvalue and the fairly low value of the Wilks'Lambda indicate good discriminatory ability of the function (table 18).

Canonical discriminant function

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation	Wilks' Lambda	Chi-square	df	Sig.
1	3,215	100	100	0,873	0,237	32,371	1	0,000

Table 18

With Fisher's linear discriminant functions (table 19) 92% of original grouped cases are correctly classified (table 20). Even if two Neanderthal samples (Combe Grenal and La Quina 18) are misclassified in the first group (Modern Human group), the molars of Taddeo Cave and Poggio Cave are still classified as Neanderthal.

Classification Function Coefficients

	Gruppo 1	2
MD1	36,64	43,90
(Constant)	-164,06	-235,24

Fisher's linear discriminant functions

Table 19

Classification Results

		Group	Predicted Group Membership 1	2	Total
Original	Count	1	16	0	16
		2	2	7	9
	%	1	100	0	100
		2	22	78	100
Cross-validated	Count	1	16	0	16
		2	2	7	9
	%	1	100	0	100
		2	22	78	100

92% of original grouped cases correctly classified.

92% of cross-validated grouped cases correctly classified.

Table 20

10.4 QUADRANTS

In table 21 the results of the ratio between the buccal and lingual part of the tooth (AB/CD) and between the distal and mesial part (BC/DA) are provided. The molars of Taddeo Cave and Poggio Cave are regarded as Neanderthal, while the molar of Fontéchevade 2 is included in the modern human group.

As you can see from the table, the number of cases used in the analysis is not always the same: it depends on the state of preservation of the crown. In fact the fifth section of the molar of Taddeo Cave does not exist.

DESCRIPTIVES						
					95% C.I. for Mean	
Variables	Group	N	Mean	S.D.	Lower Bound	Upper Bound
AB1/CD1	1	16	0,98	0,02	0,97	0,99
	2	9	0,96	0,01	0,95	0,97
BC1/DA1	1	16	0,96	0,01	0,95	0,96
	2	9	0,97	0,01	0,97	0,98
AB2/CD2	1	14	0,94	0,03	0,93	0,96
	2	9	0,99	0,03	0,96	1,01
BC2/DA2	1	14	0,90	0,04	0,88	0,92
	2	9	0,94	0,02	0,92	0,95
AB3/CD3	1	14	0,94	0,03	0,92	0,95
	2	9	1,03	0,05	0,99	1,08
BC3/DA3	1	14	0,86	0,06	0,82	0,89
	2	9	0,89	0,04	0,86	0,92
AB4/CD4	1	16	0,94	0,03	0,92	0,96
	2	9	1,08	0,07	1,03	1,13
BC4/DA4	1	16	0,84	0,05	0,81	0,87
	2	9	0,85	0,05	0,82	0,89
AB5/CD5	1	16	0,96	0,04	0,94	0,98
	2	7	1,14	0,08	1,07	1,21
BC5/DA5	1	16	0,83	0,06	0,80	0,86
	2	7	0,81	0,03	0,78	0,84

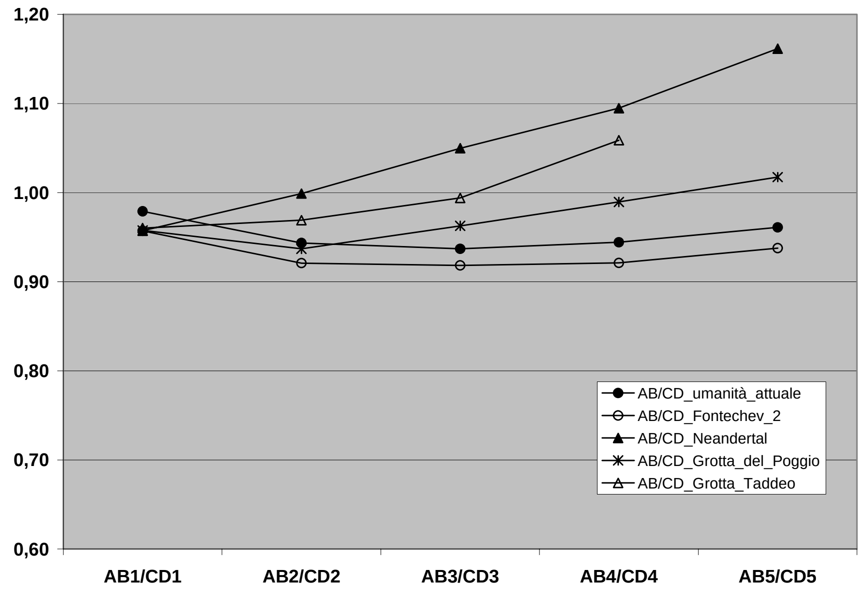
Table 21

The results of the analysis of variance (ANOVA) of the ratio between the buccal and lingual part of the crown are significantly different between the groups (Modern Human and Neanderthal). Instead this is not the same for the ratio between distal and mesial part, in which a low p value characterizes only section 1 and section 2 (table 22).

ANOVA						
Variable		Sum of Squares	df	Mean Square	F	Sig.
AB1/CD1	Between Groups	0,002	1	0,002	9,551	0,005
	Within Groups	0,005	23	0,000		
BC1/DA1	Between Groups	0,001	1	0,001	15,702	0,001
	Within Groups	0,002	23	0,000		
AB2/CD2	Between Groups	0,012	1	0,012	14,511	0,001
	Within Groups	0,017	21	0,001		
BC2/DA2	Between Groups	0,007	1	0,007	5,561	0,028
	Within Groups	0,025	21	0,001		
AB3/CD3	Between Groups	0,054	1	0,054	34,928	0,000
	Within Groups	0,033	21	0,002		
BC3/DA3	Between Groups	0,005	1	0,005	2,138	0,158
	Within Groups	0,054	21	0,003		
AB4/CD4	Between Groups	0,106	1	0,106	45,700	0,000
	Within Groups	0,053	23	0,002		
BC4/DA4	Between Groups	0,001	1	0,001	0,320	0,577
	Within Groups	0,062	23	0,003		
AB5/CD5	Between Groups	0,159	1	0,159	53,904	0,000
	Within Groups	0,062	21	0,003		
BC5/DA5	Between Groups	0,002	1	0,002	0,825	0,374
	Within Groups	0,055	21	0,003		

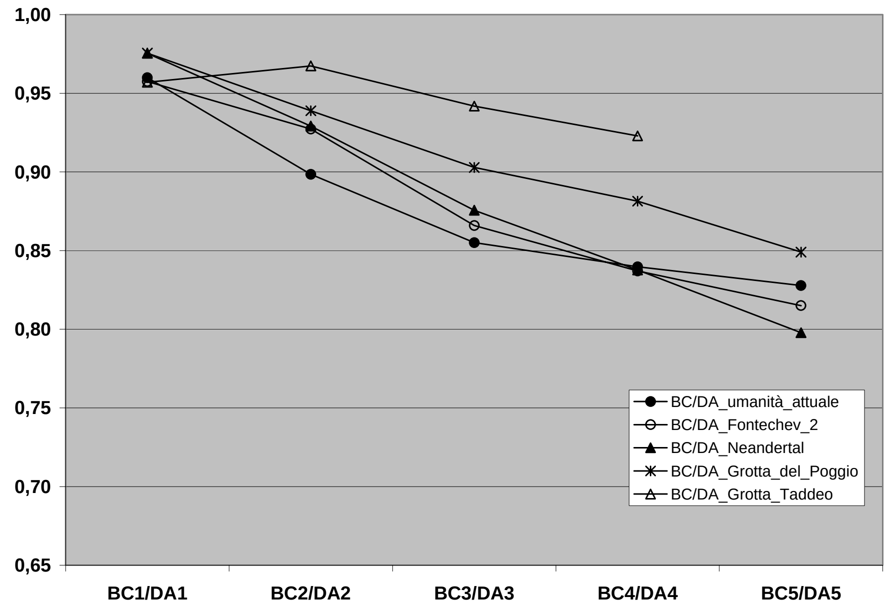
Table 22

In graphics 2 and 3 the mean values of the ratio respectively AB/CD (graphic 2) and BC/DA (graphic 3) are provided, maintaining the molars of Taddeo Cave, Poggio Cave and Fontéchevade 2 separate from the major groups. In the first graphic the line of the Neanderthal sample is completely different from that of the Modern Human sample. In fact, at times starting from the second section but mainly from the third one, values above the unit characterize the Neandertal group; instead, the values of the Modern Human group are always lower than the unit. In regards to the centroid of the first section, we can suppose that in the Neanderthal first molar the buccal part of the crown is more developed than the lingual one. Whilst the molar of Poggio Cave is in the middle between the Neanderthal and Modern Human line, the molar of Taddeo Cave is nearer to the Neanderthal group.
Indeed, it is worthy to note the molar of Fontéchevade 2, whose line is almost parallel to the Modern Human one.



Graphic 2. Bucco-lingual ratio (AB/CD)

As already seen in the analysis of variance in regard on BC/DA ratio, there is not a significant difference in the trend of the line of the two groups. A gradual decrease of the ratio with values under the unit characterize both the groups (graphic 3). On the bases of the centroid of the first section, in Modern Human and in Neanderthal upper M1 it seems that there is not a difference way in the development of the distal part of the crown in comparison with the mesial part: from the first section to the five section, the low value of the ratio means that it is bigger the development of the mesial component than the distal one. In this uncertain picture the lines of Taddeo Cave and Poggio Cave are slightly above the other lines, but in any case they follow the same decreasing trend.



Graphic 3. Disto-mesial ratio (BC/DA)

CONCLUSION

As explained in the first part of this dissertation and especially considering the results showed in the second part, three-dimensional geometric models of the teeth provide the best solution for morphological and morphometric analysis. The necessity to study the molars of Taddeo Cave and Poggio Cave (near Marina di Camerota, Salerno), not exhaustively investigated with the traditional approach, has called for the definition of a new methodology based on three-dimensional virtual reconstruction of the teeth. While it is clear that the molar of Poggio Cave doesn't belong to Modern Human species, until now there has not been this certainty for the molars of Taddeo Cave, for which different interpretations have been provided.

The first problem to resolve was the standardization of an orientation system for comparing the first molars. For this reason a virtual data base of Modern Human first molars has been created. For the first lower molar eight orientation systems have been compared and an orientation system has been chosen based on lingual-mesial-distal cervical points. On the other hand, for the first upper molars six orientation systems have been compared and a system has been chosen based on mesial-distal-buccal cervical points. In general, these cervical points allow us to use the orientation systems in worn teeth. Indeed, starting from the lingual cervical point (for the lower first molars) and the buccal cervical point (for the upper first molar), multiple sections of the crown with a step of 1 millimetre have been made.

Only a few millimetres of the crown have been considered. In particular, 4 millimetres (5 sections) for the first lower molar and only 3 millimetres (4 sections) for the first upper molar. In this last case the reduction is due to the heavy wear of the molar of Taddeo Cave. As a Neanderthal sample, 7 upper first molars and 7 lower first molars have been scanned, oriented using the new methodology and finally multiple sections were obtained.

Through a principal component analysis the molars of Taddeo Cave and Poggio Cave have been positioned inside the Neanderthal group using the first two principal components.

At the same time, discriminant analyses were carried out in order to understand the best variables that could be involved in human species classification.

In regard to the first lower molar, 3 millimetres of crown are enough for a correct classification of all cases, and the molar of Taddeo Cave comes out as Neanderthal. Under these conditions 3 variables have been selected: a size variable and 2 shape variables. It is worthwhile to note that the size variable is the BL diameter of the 4 section, while the two shape variables are the BL/MD ratio of the first section and Ix/Iy ratio of the second section. Indeed, even if only 1 millimetre of crown is preserved (two sections), 3 variables are always

selected and good results are obtained (100% of original cases are correctly classified, and 92% in a cross-validation analysis). Again, in this extreme condition, the lower molar of Taddeo Cave is considered as Neanderthal.
A further analysis based on the repartition of the crown by means of two orthogonal planes passing through the centroid of the first section has been carried out. Leaving the first section out of consideration, the repartition of the other sections in a buccal, lingual, mesial and distal part could explain the development of the crown in relation to the first section. While the bucco-lingual ratio (AB/CD) is not significantly different between Neanderthal and Modern Human (except for the four section), it has been found that the disto-mesial ratio (BC/DA) of the second and third section are different. What is more, the two ratios of the molar of Taddeo Cave overlap those of the Neanderthal group.
In regard to the first upper molar, 3 millimetres of the crown (4 sections) give us the possibility to classify correctly all the cases, and the molar of Taddeo Cave comes out as Neanderthal. Logically, considering that only two major groups were created (Neanderthal and Modern Human), the upper molar of Poggio Cave comes out as Neanderthal. By means of a discriminant analysis two variables are selected, both relative to the size of the tooth: a diameter (BL4) and an area (A3).
It is interesting to note that using the first section, that it is the worst condition, the MD diameter (MD1) correctly classifies 92% of original grouped cases. The upper first molars of Taddeo Cave and Poggio Cave are always ascribed in the Neanderthal group.
Finally, the crown subdivision by means of two orthogonal planes provides some interesting results. Unlike the lower first molar, the AB/CD ratio always has significant differences in all the four involved sections, while the BC/DA ratio doesn't give any contribution to the differentiation of the two groups. Possibly the higher values of the Neanderthal group for the AB/CD ratio means a bigger enlargement of the buccal part in Neanderthal upper first molar than in Modern Human in relation to the first section. It is clear that the molar of Taddeo Cave shows a trend like that of the Neanderthal one, while the trend of the molar of Poggio Cave is more ambiguous, positioned between Neanderthal and Modern Human group.
For this reason we can ascribe the molars of Taddeo Cave inside the Neanderthal group, while a better classification of the molar of Poggio Cave (here considered as Neanderthal) needs the enlargement of the sample with other fossil human species.
It is important to remark here that the three-dimensional approach may encourage different kinds of research, and in this thesis only an portion of them have been discussed. In the near future other dental typologies should be investigated, standardizing different orientation

systems and improving useful analyses on the virtual geometrical models. Improving this three-dimensional approach could provide a valid contribution for species classification and in general a useful tool for better understanding our phylogenetic evolution.

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ATTACHMENTS

LOWER M1

	SECTION 1									
SAMPLE	Length S1	A1	Quadrant area				Second moment		BL	MD
			A	B	C	D	Ix	Iy		
M1_inf_6_L	33,37	83,63	21,91	19,96	21,29	20,48	561,86	563,11	10,00	10,10
M1_inf_21_L	31,52	72,73	19,30	16,87	18,87	17,68	452,40	403,23	9,60	9,05
M1_inf_27_L	36,09	94,89	24,67	22,70	24,37	23,16	750,67	708,17	10,64	10,32
M1_inf_32_R	31,14	71,21	19,01	16,79	18,44	16,97	435,75	385,61	9,34	8,95
M1_inf_34_R	32,07	75,32	19,57	18,06	19,17	18,52	483,11	433,80	9,62	9,02
M1_inf_37_L	32,65	76,30	20,72	17,71	20,15	17,71	504,57	444,75	9,77	9,20
M1_inf_58_L	33,01	76,90	19,91	18,54	19,27	19,18	476,78	486,74	9,49	9,40
M1_inf_84_L	34,73	88,56	23,20	21,08	22,84	21,44	649,50	617,02	10,26	10,13
M1_inf_85_R	35,28	88,93	23,38	21,28	22,73	21,55	622,28	665,53	10,03	10,38
M1_inf_87_R	34,27	88,39	23,32	20,66	22,89	21,52	621,91	637,12	10,16	10,34
M1_inf_90_L	32,88	80,97	21,46	19,09	20,74	19,58	550,44	504,79	10,05	9,60
M1_inf_91_L	34,31	85,68	23,44	19,86	22,90	19,47	577,83	619,02	9,84	10,43
M1_inf_93_L	32,10	76,22	20,94	17,36	20,46	17,45	504,31	441,01	9,81	9,25
M1_inf_95_L	31,86	72,43	18,77	17,21	18,28	18,17	441,02	412,28	9,52	9,00
M1_inf_96_L	31,63	73,62	19,01	17,39	10,03	18,20	442,32	431,56	9,40	9,26
Les_Rois_R50_4_R_U.P.	35,98	93,51	24,74	22,30	24,15	22,32	685,61	722,54	10,31	10,92
Qafzeh_3_L_U.P.	32,78	80,50	21,05	19,22	20,80	19,43	516,13	527,03	9,61	9,89
Petit_Puy_3_R_neand	33,55	82,60	21,32	19,80	21,31	20,18	553,43	544,71	9,98	9,93
Devils_Tower_R_neand	35,41	94,48	24,14	23,03	24,13	23,18	726,42	705,79	10,55	10,47
Krapina_077_R_neand	39,40	111,44	30,66	25,04	30,80	24,94	1077,94	965,71	12,03	11,08
Krapina_079_R_neand	40,13	120,02	30,23	30,42	29,18	30,19	1135,14	1184,03	11,59	11,94
Krapina_80_R_neand	35,63	94,68	25,24	22,23	25,31	21,89	740,11	704,16	10,81	10,57
Krapina_81_L_neand	35,29	92,78	24,02	22,42	23,95	22,39	697,05	691,32	10,34	10,28
Vindija_226_L_neand	33,20	81,45	21,02	20,22	20,33	19,88	547,21	517,41	10,08	9,91
Taddeo_Cave_R	36,82	96,25	25,13	23,46	24,81	22,86	737,47	766,74	10,60	10,77

	SECTION 2									
SAMPLE	Length S2	A2	Quadrant area				Second moment		BL	MD
			A	B	C	D	Ix	Iy		
M1_inf_6_L	34,82	92,31	23,65	20,76	23,63	24,26	661,83	703,21	10,40	10,88
M1_inf_21_L	34,12	85,54	21,63	18,83	23,02	22,05	615,57	561,56	10,33	9,97
M1_inf_27_L	37,25	104,00	25,79	23,75	28,01	26,44	889,61	847,90	11,29	10,99
M1_inf_32_R	33,14	82,91	22,04	19,06	21,39	20,42	569,59	526,13	10,07	9,80
M1_inf_34_R	33,22	81,51	21,73	19,07	20,56	20,14	564,02	505,27	9,97	9,45
M1_inf_37_L	34,01	84,74	23,97	19,96	21,07	19,74	603,58	558,34	10,18	9,91
M1_inf_58_L	34,79	89,98	22,98	21,32	22,38	23,30	657,28	647,82	10,21	10,12
M1_inf_84_L	36,75	100,93	25,70	22,93	26,80	25,50	829,09	810,31	10,90	10,82
M1_inf_85_R	36,67	100,07	26,41	24,35	24,96	24,35	769,95	846,61	10,52	11,03
M1_inf_87_R	35,81	97,95	26,31	21,88	24,55	25,21	748,85	788,96	10,65	11,08
M1_inf_90_L	34,16	88,95	22,81	20,94	23,27	21,94	651,49	618,64	10,46	10,16
M1_inf_91_L	35,33	93,55	25,16	21,51	24,40	22,49	677,64	736,11	10,20	10,92
M1_inf_93_L	33,39	83,73	22,98	18,64	21,81	20,29	599,10	532,37	10,38	9,80
M1_inf_95_L	33,04	81,31	21,23	18,24	20,26	21,57	551,40	512,70	10,03	9,66
M1_inf_96_L	33,52	83,84	21,02	18,29	22,29	22,24	555,27	573,27	9,91	10,08
Les_Rois_R50_4_R_U.P.	37,63	103,65	27,29	24,67	26,52	25,18	815,72	908,80	10,83	11,78
Qafzeh_3_L_U.P.	34,53	89,77	24,93	21,02	21,59	22,23	636,14	657,71	10,18	10,58
Petit_Puy_3_R_neand	35,65	95,86	24,51	22,93	24,79	23,64	702,39	770,81	10,58	11,04
Devils_Tower_R_neand	36,62	103,54	26,75	25,22	25,66	25,92	832,02	882,22	10,89	11,28
Krapina_077_R_neand	40,45	121,00	33,15	27,52	32,59	27,74	1237,40	1147,71	12,33	11,58
Krapina_079_R_neand	41,11	128,35	32,84	31,89	30,87	32,74	1276,44	1368,61	11,95	12,52
Krapina_80_R_neand	38,27	111,20	29,00	25,71	29,90	26,59	994,30	991,10	11,62	11,60
Krapina_81_L_neand	36,54	101,36	25,87	24,62	26,12	24,75	813,10	836,52	10,73	10,92
Vindija_226_L_neand	34,35	89,59	22,71	22,25	22,67	21,96	631,47	652,69	10,08	9,91
Taddeo_Cave_R	38,40	106,98	27,95	26,07	27,21	25,75	888,57	953,27	11,09	11,48

U.P. = Upper Paleolithic

	SECTION 3									
SAMPLE	Length S3	A3	Quadrant area				Second moment		BL	MD
			A	B	C	D	Ix	Iy		
M1_inf_6_L	36,58	102,40	26,00	22,10	26,23	28,08	764,56	918,68	10,70	11,92
M1_inf_21_L	35,38	94,23	23,81	19,76	25,07	25,59	713,55	710,36	10,74	10,69
M1_inf_27_L	38,38	112,19	26,74	24,94	31,03	29,48	997,11	1017,54	11,47	11,70
M1_inf_32_R	34,79	92,33	23,53	20,32	24,78	23,70	657,38	688,48	10,45	10,68
M1_inf_34_R	34,21	88,39	23,70	20,18	22,23	22,28	634,64	617,82	10,29	10,16
M1_inf_37_L	34,95	92,21	25,65	21,66	23,02	21,87	663,84	703,24	10,34	10,74
M1_inf_58_L	36,01	97,76	24,60	22,01	24,63	26,52	757,78	776,70	10,47	10,68
M1_inf_84_L	38,16	109,57	27,02	23,64	29,59	29,32	936,64	990,21	11,11	11,56
M1_inf_85_R	38,19	109,45	28,54	25,88	27,62	27,40	880,69	1048,03	10,89	11,87
M1_inf_87_R	37,65	108,87	29,53	23,13	26,57	29,64	889,06	1009,24	11,09	11,95
M1_inf_90_L	35,26	95,06	24,18	21,58	25,06	24,23	712,14	735,61	10,74	10,82
M1_inf_91_L	36,53	100,90	26,43	22,79	26,15	25,54	752,38	888,30	10,46	11,54
M1_inf_93_L	34,70	91,34	25,15	19,93	23,34	22,91	674,64	665,93	10,60	10,52
M1_inf_95_L	34,53	90,37	23,37	19,00	22,70	25,30	660,14	648,43	10,42	10,31
M1_inf_96_L	34,16	88,96	22,29	18,90	23,46	24,31	591,24	678,83	9,94	10,66
Les_Rois_R50_4_R_U.P.	39,01	110,94	28,04	25,46	28,92	28,53	880,21	1102,87	11,00	12,46
Qafzeh_3_L_U.P.	36,43	100,81	28,30	22,42	23,29	26,80	793,47	835,53	10,76	11,21
Petit_Puy_3_R_neand	37,96	108,62	26,66	24,74	28,92	28,29	867,51	1022,75	11,13	12,10
Devils_Tow er_R_neand	37,78	110,87	29,15	26,22	26,98	28,52	921,28	1044,75	11,13	11,97
Krapina_077_R_neand	41,10	127,15	34,70	28,74	33,76	29,95	1319,70	1294,17	12,48	12,09
Krapina_079_R_neand	42,55	138,10	36,51	33,82	32,34	35,43	1462,93	1595,08	12,39	13,07
Krapina_80_R_neand	40,07	124,00	31,37	27,40	33,39	31,85	1197,80	1263,40	12,09	12,51
Krapina_81_L_neand	37,22	105,87	26,70	25,07	27,34	26,75	862,99	933,32	10,95	11,42
Vindija_226_L_neand	35,23	93,73							10,40	11,31
Taddeo_Cave_R	39,92	116,62	30,48	28,02	29,28	28,85	1011,36	1175,36	11,37	12,26

	SECTION 4									
SAMPLE	Length S4	A4	Quadrant area				Second moment		BL	MD
			A	B	C	D	Ix	Iy		
M1_inf_6_L	37,91	106,72	25,74	22,37	27,67	30,94	778,14	1067,33	10,70	12,45
M1_inf_21_L	35,26	94,07	23,10	18,63	25,10	27,25	668,17	752,61	10,52	11,00
M1_inf_27_L	38,63	114,10	26,80	24,36	32,04	30,90	982,96	1103,13	11,36	12,18
M1_inf_32_R	35,12	94,04	23,29	19,77	25,93	25,05	647,76	765,88	10,20	11,19
M1_inf_34_R	35,06	92,73	23,84	20,27	24,10	24,52	642,22	738,45	10,11	10,90
M1_inf_37_L	35,80	96,36	26,23	22,30	24,40	23,43	676,00	820,57	10,28	11,45
M1_inf_58_L	36,82	103,09	25,15	22,27	26,75	28,92	803,80	901,35	10,59	11,30
M1_inf_84_L	38,51	111,00	26,46	22,76	30,56	31,21	910,71	1071,47	10,99	12,00
M1_inf_85_R	39,02	114,25	28,78	25,98	29,76	29,73	904,50	1208,67	10,90	12,52
M1_inf_87_R	38,26	112,90	29,74	23,30	27,76	32,10	909,07	1139,10	11,03	12,84
M1_inf_90_L	35,81	97,37	23,98	20,82	26,19	26,38	697,72	826,01	10,54	11,36
M1_inf_91_L	37,44	105,79	26,30	23,26	27,66	28,58	774,94	1034,35	10,52	12,21
M1_inf_93_L	35,51	95,64	24,99	20,18	24,83	25,64	693,33	774,24	10,48	11,10
M1_inf_95_L	35,23	94,29	23,61	19,44	24,32	26,92	691,05	733,00	10,41	10,73
M1_inf_96_L	33,72	84,32	20,62	17,00	22,73	23,97	497,68	653,99	9,42	10,81
Les_Rois_R50_4_R_U.P.	39,79	111,36	25,71	25,21	30,14	30,30	850,76	1171,72	10,94	12,65
Qafzeh_3_L_U.P.	37,33	106,44	28,35	22,10	25,53	30,45	865,24	952,12	10,92	11,40
Petit_Puy_3_R_neand	38,96	115,53	27,14	24,18	31,98	32,23	947,62	1200,14	11,27	12,86
Devils_Tow er_R_neand	38,60	114,86	30,44	26,31	27,58	30,53	941,73	1177,55	11,08	12,61
Krapina_077_R_neand	41,85	133,36	35,67	29,28	35,63	32,77	1389,90	1475,39	12,51	12,73
Krapina_079_R_neand	43,80	145,73	38,32	34,86	34,08	38,48	1605,61	1803,11	12,73	13,49
Krapina_80_R_neand	40,70	128,67	32,02	27,82	34,34	34,49	1266,43	1381,22	12,23	12,95
Krapina_81_L_neand	38,25	111,86	28,06	25,40	28,70	29,70	927,06	1080,91	11,12	12,01
Vindija_226_L_neand										
Taddeo_Cave_R	40,82	121,16	31,25	28,10	30,83	30,98	1050,47	1311,72	11,51	12,77

SAMPLE	SECTION 5									
	Length S5	A5	Quadrant area				Second moment		BL	MD
			A	B	C	D	Ix	Iy		
M1_inf_6_L	38,30	106,25	24,17	21,87	28,19	32,02	745,44	1099,63	10,63	12,66
M1_inf_21_L	34,69	86,49	20,28	15,90	23,58	26,73	529,57	684,81	9,76	10,97
M1_inf_27_L	37,82	106,70	23,77	21,26	31,31	30,40	807,09	1032,44	10,79	12,26
M1_inf_32_R	34,74	89,26	21,69	18,40	24,74	24,42	557,01	737,30	9,69	11,27
M1_inf_34_R	35,16	92,73	23,31	19,76	24,43	25,23	606,02	784,27	9,81	11,24
M1_inf_37_L	35,55	94,40	25,21	21,61	24,09	23,50	618,68	826,22	9,98	11,50
M1_inf_58_L	36,93	103,85	23,94	21,63	28,02	30,27	775,13	959,05	10,56	11,72
M1_inf_84_L	38,23	105,57	24,26	21,14	29,37	30,79	781,79	1025,69	10,52	12,17
M1_inf_85_R	39,03	112,94	27,55	25,44	29,76	30,19	849,38	1230,77	10,63	12,65
M1_inf_87_R	38,19	108,91	27,78	21,79	26,97	32,38	801,74	1120,68	10,64	12,60
M1_inf_90_L	35,74	96,21	23,06	20,16	26,30	26,69	650,50	845,84	10,16	11,58
M1_inf_91_L	38,06	107,92	26,16	23,92	27,92	29,92	777,48	1115,83	10,55	12,58
M1_inf_93_L	35,30	93,81	23,29	19,47	24,81	26,24	636,36	779,66	10,18	11,19
M1_inf_95_L	34,71	88,83	20,84	17,39	23,91	26,67	569,95	702,33	9,73	10,79
M1_inf_96_L	32,46	73,99	17,49	14,23	20,53	21,74	360,36	541,34	8,64	10,56
Les_Rois_R50_4_R_U.P.	38,92	107,36	23,94	23,48	29,56	30,39	762,31	1126,95	10,57	12,48
Qafzeh_3_L_U.P.										
Petit_Puy_3_R_neand	39,26	112,25	25,30	20,97	32,61	33,37	879,44	1162,91	11,11	12,93
Devils_Tow er_R_neand	38,84	113,41	29,91	24,77	27,67	31,06	884,10	1198,14	10,87	12,78
Krapina_077_R_neand	41,63	131,99	34,72	28,41	35,48	33,37	1312,12	1497,52	12,27	12,99
Krapina_079_R_neand	44,52	145,77	37,98	32,90	34,96	39,93	1578,85	1841,51	12,64	13,67
Krapina_80_R_neand	40,40	123,62	30,11	26,03	33,18	34,30	1135,00	1315,15	11,84	12,97
Krapina_81_L_neand	38,69	112,92	28,00	24,54	29,22	31,16	918,02	1136,86	11,05	12,31
Vindija_226_L_neand										
Taddeo_Cave_R	40,88	116,95	29,64	26,27	30,35	30,69	949,65	1257,28	11,18	12,71

UPPER M1

	SECTION 1									
SAMPLE	Length S1	A1	Quadrant area				Second moment		BL	MD
			A	B	C	D	Ix	Iy		
M1_97_R	34,74	86,14	22,26	20,41	21,66	21,81	808,25	447,91	11,85	8,75
M1_94_R	36,16	88,97	24,45	19,96	23,77	20,78	868,43	493,80	11,72	9,24
M1_92_R	36,45	93,12	24,9	20,57	25,05	22,6	919,14	546,39	12,02	9,44
M1_89_R	34,34	84,57	22,69	19,14	22,1	20,64	761,61	444,11	11,63	8,97
M1_88_R	35,4	89,94	25,97	18,99	25,17	19,81	828,75	535,37	11,77	9,72
M1_86_L	34,08	83,53	22,6	18,49	22,07	20,38	712,11	456,28	11,34	8,99
M1_83_R	34,71	83,36	22,4	18,85	21,89	20,22	731,58	438,37	11,5	8,87
M1_76_L	33,22	78,15	21,02	17,45	21,04	18,63	667,65	367,19	11,18	8,38
M1_63_L	34,24	81,92	22,5	17,66	22,71	19,05	736,47	413,94	11,28	8,85
M1_59_R	34,22	79,99	21,63	18,32	20,43	19,61	706,76	387,22	11,7	8,66
M1_56_L	34,57	84,06	22,79	19,07	22,25	19,94	753,21	440,34	11,48	8,66
M1_33_L	33,41	78,59	21,07	17,61	20,93	18,98	633,67	400,39	10,87	8,68
M1_31_R	32,9	77,16	20,55	17,82	20,05	18,74	629,25	370,77	10,91	8,45
M1_16_R	34,76	84,7	22,64	19,04	22,6	20,4	790,23	431,06	11,63	8,8
M1_07_L	32,55	75,93	20,71	16,81	20,35	18,06	609,66	361,97	10,93	8,54
SPY_2_L_neand	38,95	107,1	29,64	23,03	29,72	24,72	1122,30	789,06	12,33	10,89
Combe_Grenal_R_neand	36,19	92,26	25,72	19,54	26,11	20,88	877,00	555,28	11,94	9,73
Krapina_134_R_neand	40,62	114,36	32,34	23,37	32,91	25,73	1260,91	945,96	12,81	11,4
Krapina_136_L_neand	41,7	122,29	34,63	26,08	34,49	27,1	1584,92	956,62	13,96	11,09
Krapina_164_L_neand	37,41	99,39	27,37	20,72	28,33	22,96	937,25	710,04	11,82	10,52
Krapina_171_R_neand	38,34	100,61	28,65	20,37	29,33	22,25	955,07	751,56	12,04	10,8
La_Quina_18_R_neand	35,71	91,67	24,95	19,6	25,69	21,42	853,76	555,35	11,72	9,62
Fontechev_2_L_U.P.	38,28	103,07	26,64	23,77	26,65	26,02	1182,47	635,25	13	9,67
Poggio_Cave_L	42,59	120,32	32,36	26,49	32,92	28,54	1433,70	980,25	13,24	11,19
Taddeo_Cave_R	38,54	105,87	30,05	21,81	29,96	24,05	1078,39	801,56	12,27	10,92

	SECTION 2									
SAMPLE	Length S2	A2	Quadrant area				Second moment		BL	MD
			A	B	C	D	Ix	Iy		
M1_97_R	35,88	93,53	24,4	20,89	24,07	24,17	915,54	548,07	12,09	9,46
M1_94_R	38,28	102,9	29,19	21,14	26,72	25,85	1086,82	690,90	12,28	10,13
M1_92_R	37,48	102,33	27,27	21,66	27,34	26,05	1043,81	690,80	12,25	10,16
M1_89_R	35,6	92,67	24,74	20,32	24,47	23,15	865,60	560,56	11,93	9,68
M1_88_R	36,82	100,4	30,32	19,68	26,27	24,14	960,59	709,51	12,03	10,69
M1_86_L	35,18	90,66	24,97	19,55	23,39	22,75	793,82	562,71	11,51	9,51
M1_83_R									12,14	9,77
M1_76_L	34,74	88,33	24,68	18,37	22,68	22,59	796,01	498,19	11,55	9,34
M1_63_L	36,34	94,6	25,42	19,39	26,67	23,12	919,11	583,30	11,9	9,81
M1_59_R										
M1_56_L	36,65	95,77	25,83	20,53	25,4	24,01	940,86	592,70	11,95	9,52
M1_33_L	35,22	90,77	24,08	18,65	24,7	23,33	787,19	567,59	11,24	9,83
M1_31_R	34,69	87,59	23,26	19,63	22,9	21,8	770,43	500,02	11,31	9,28
M1_16_R	36,02	92,2	25,96	19,05	22,88	24,31	894,90	533,77	12,01	9,5
M1_07_L	34,04	83,88	23,87	17,12	21,57	21,31	692,25	474,03	11,08	9,39
SPY_2_L_neand	40,11	117,64	32,87	25,45	31,89	27,43	1293,41	987,95	12,58	11,62
Combe_Grenal_R_neand	37,34	103,47	29,3	22,52	28,15	23,5	1034,39	732,83	12,32	10,6
Krapina_134_R_neand	42,3	126,02	37,51	25,24	34,1	29,17	1438,58	1208,85	13,03	12,29
Krapina_136_L_neand	43,53	134,44	40,36	28,75	36,35	28,97	1784,35	1254,87	14,1	12,13
Krapina_164_L_neand	39,82	114,03	32,72	23,89	30,99	26,43	1182,34	964,68	12,44	11,46
Krapina_171_R_neand	40,82	117,17	34,71	23,69	32,07	26,7	1213,28	1075,91	12,52	11,94
La_Quina_18_R_neand	36,85	99,9	28,09	21,26	26,84	23,69	955,53	692,69	11,9	10,41
Fontechev_2_L_U.P.	39,09	109,97	28,46	24,26	28,65	28,6	1297,61	746,91	13,22	10,29
Poggio_Cave_L	44,7	133,8	36,55	28,17	36,62	32,46	1669,53	1293,17	13,7	12,26
Taddeo_Cave_R	39,36	113,3	32,17	23,59	32,12	25,42	1173,34	959,20	12,45	11,53

	SECTION 3									
SAMPLE	Length S3	A3	Quadrant area				Second moment		BL	MD
			A	B	C	D	Ix	Iy		
M1_97_R	36,19	97,52	26,47	20,55	25,2	25,3	902,06	653,28	11,8	10,16
M1_94_R	39,37	113,78	32,52	22,37	29,43	29,46	1227,60	901,03	12,5	11,07
M1_92_R	37,95	106,34	28,16	22,04	28,55	27,59	1066,33	783,58	12,22	10,64
M1_89_R	35,94	96,06	25,61	20,47	25,47	24,52	854,36	651,12	11,69	10,27
M1_88_R	38,64	111,89	34,69	20,91	28,17	28,12	1118,65	935,24	12,28	11,56
M1_86_L	36,32	98,2	27,45	21,01	24,82	24,93	845,52	719,24	11,49	10,41
M1_83_R									12,31	10,96
M1_76_L	36,24	97,73	28,76	18,73	24,16	26,08	893,68	663,87	11,73	10,35
M1_63_L	37,21	103,02	27,99	20,89	28,31	25,83	1006,36	737,52	12	10,6
M1_59_R										
M1_56_L	38,17	106,93	29,52	22,91	27,91	27,48	1094,17	784,40	12,31	10,55
M1_33_L	36,61	100,16	27,75	19,98	26,45	25,98	881,38	745,14	11,46	10,86
M1_31_R	35,96	95,9	26	20,54	25,08	24,28	849,04	649,99	11,39	10,15
M1_16_R	37,06	100,38	29,8	19,43	23,74	27,41	974,84	681,00	12,1	10,35
M1_07_L	35,01	89,74	26,04	17,14	22,79	23,77	731,19	584,43	11,02	10,16
SPY_2_L_neand	40,67	120,44	33,98	26,2	32,15	28,12	1295,07	1087,55	12,48	12,04
Combe_Grenal_R_neand	38,18	110,23	32,41	23,68	28,72	25,42	1079,30	900,44	12,17	11,36
Krapina_134_R_neand	44,31	138,5	43,31	26,84	35,48	32,87	1614,78	1564,61	13,17	13,36
Krapina_136_L_neand	45,07	145,53	47,03	30,93	36,86	30,71	1938,39	1591,88	14,22	13,28
Krapina_164_L_neand	40,8	122,92	37,04	25,56	31,82	28,51	1310,74	1170,62	12,55	12,2
Krapina_171_R_neand	42	128,54	39,87	25,68	33,31	29,68	1390,73	1338,42	12,8	12,76
La_Quina_18_R_neand	37,39	105,23	31,39	22,65	26,32	24,88	973,29	828,48	11,74	11,21
Fontechev_2_L_U.P.	39,37	114,13	31,03	23,61	29,36	30,14	1281,18	868,86	12,99	10,68
Poggio_Cave_L	46,66	144,91	40,97	30,1	38,65	35,18	1872,81	1582,59	14,03	13,06
Taddeo_Cave_R	39,91	115,9	33,41	24,36	31,85	26,27	1205,65	1019,08	12,43	11,83

	SECTION 4									
SAMPLE	Length S4	A4	Quadrant area				Second moment		BL	MD
			A	B	C	D	Ix	Iy		
M1_97_R	36,37	99,45	27,6	20,28	25,53	26,04	847,72	750,17	11,38	10,75
M1_94_R	39,9	118,44	34,01	23,03	30,32	31,09	1230,40	1049,06	12,36	11,9
M1_92_R	38,14	108,01	29,07	21,59	29,09	28,26	1000,97	885,06	11,94	11,12
M1_89_R	36,07	96,1	26,02	19,76	25,46	24,86	768,96	726,12	11,11	10,83
M1_88_R	39,59	117,72	37,27	22,03	28,72	29,7	1170,58	1091,13	12,23	12,14
M1_86_L	36,58	100,39	28,59	21,61	25,08	25,11	811,27	815,87	11,14	10,99
M1_83_R	39,15	114,21	31,5	23,7	29,53	29,49	1106,35	1000,62	12	11,51
M1_76_L	37,18	102,61	31,13	18,93	25,03	27,52	906,92	799,62	11,54	11,03
M1_63_L	37,35	105,44	28,8	21,48	28,68	26,48	964,45	837,33	11,76	11,11
M1_59_R	37,15	101,46	27,67	21,73	25,81	26,25	881,41	783,75	11,55	10,8
M1_56_L	38,82	112,28	31,28	23,24	28,69	29,07	1113,54	928,08	12,16	11,23
M1_33_L	37,14	102,98	29,22	20,62	26,61	26,53	854,94	857,27	11,29	11,37
M1_31_R	36,51	99,77	27,66	20,91	26,05	25,14	851,23	761,44	11,23	10,73
M1_16_R	37,85	104,76	31,9	20,02	24,02	28,82	974,65	807,08	11,74	10,91
M1_07_L	35,08	90,36	26,57	17,13	22,69	23,96	681,58	644,03	10,54	10,6
SPY_2_L_neand	40,86	116,84	33,58	25,44	30,09	27,73	1188,81	1049,56	12,12	12,03
Combe_Grenal_R_neand	38,12	110,52	33,27	23,48	27,88	25,9	1009,50	971,01	11,8	11,78
Krapina_134_R_neand	45,42	148,12	46,98	28,98	36,35	35,81	1769,34	1847,10	13,33	14,14
Krapina_136_L_neand	45,86	153,15	50,57	33,66	36,62	32,3	2004,18	1867,78	14,12	14,02
Krapina_164_L_neand	41,14	124,45	39,08	25,72	30,3	29,35	1303,07	1238,36	12,35	12,52
Krapina_171_R_neand	42,25	129,84	41,46	26,28	31,96	30,14	1374,34	1403,77	12,68	13,13
La_Quina_18_R_neand	37,11	102,32	32,36	22,03	24,11	23,83	848,82	850,69	11,17	11,49
Fontechev_2_L_U.P.	39,06	113,88	31,84	22,76	29,13	30,15	1157,20	947,42	12,53	11,17
Poggio_Cave_L	47,89	151,35	43,62	31,66	39,25	36,83	1949,26	1812,50	14,04	13,73
Taddeo_Cave_R	39,53	112,5	33,59	24,26	29,73	24,91	1109,17	986,24	12,1	11,73

ACKNOWLEDGES

Thank you to all the people that in these last 3 years have given me the possibility to bring to fruition this research.
Thank you to Professor Francesco Mallegni, who kindly provided me with the teeth from Taddeo Cave and Poggio Cave, which provided the impetus for this research.
Thank you to Professor Peter Ungar, who invited me to his Paleoanthropology Laboratory at the Arkansas University in order to complete my research.
Thank you to Professor Erik Trinkaus, who kindly provided me with a number of Neanderthal molars in order to create an initial paleoanthropological data base.
Thank you to Massimiliano, with whom I have begun a mutually beneficial collaboration.
Thank you to Professor Giorgio Gruppioni, who has always encouraged me and motivated my research.
Thank you to all the people who have contributed to the realization of this thesis: Giovanna, Cristina, Giorgia, Charles, Teresa, Elisabetta and Monica;
Thank you to my family, for all the patience they have had with me.
And finally, thank you to Benedetta, the one person that always gives me the ability and perseverance to face the troubles and challenges of life.