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A pattern of metatarsal bovine bone surface alterations produced by human permanent teeth - An experimental approach

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ABSTRACT

The research of human induced tooth marks on bone surface represents a promising field of investigation of high interest for archaeologists. The aim of this study was to address the issue of equifinality of tooth marks recognition and analysis using experimental setup involving permanent teeth. Five volunteers mouthed and chewed fresh metatarsal bovine bone. A total of > 2000 marks were recorded and the type, geometry and metrics reported. Differences between tooth type and intensity level employed for marks formation were also described. The obtained data may support the identification and recognition of human tooth marks in the archaeological context.

1. Introduction

The research of human induced tooth marks on bone surface represents a promising field of investigation of high interest for archaeologists. The importance of explaining the effects of interaction processes involving human teeth and animal bone materials is of great significance when it comes to archaeological interpretation. Additionally, the elucidation of these interactions is of particular interest for research fields that are closely connected to taphonomy, especially the influences of human mastication processes on bone surfaces, “which can help to detect anthropogenic interventions in the formation and disturbance of bone assemblages” (Fernández-Jalvo and Andrews, 2011; Romero et al., 2016; Marin-Monfort et al., 2018).

There are many reports focusing on explaining the pattern in which hominids may leave behind archaeologically observable tooth marks (Landt, 2007; Delaney-Rivera et al., 2009; Fernández-Jalvo and Andrews, 2011; Andrés et al., 2012; Saladié et al., 2013; Domínguez-Rodrigo et al., 2014; Starkovich and Conard, 2015; Young et al., 2015; Fernández-Jalvo and Andrews, 2016; Romero et al., 2016). Regarding the tooth marks on skeletal elements, more than three decades ago microscopic and macroscopic criteria had been established for designation of “non-tooth marked” as well as “tooth marked” bone samples, and have been consistently used with variations and improvements (Potts and Shipman, 1981). Despite the completely different experimental and analytical setups employed in these reports, there is consensus that evidence of human chewing is not an easy task when it comes to distinguishing it from other animal chewing or other similar taphonomic alterations (Pesquero et al., 2017).

Tooth mark analysis requires multidisciplinary approach, since it stays at the intersection of at least four scientific disciplines: anthropology, forensics, archaeology and dental science. In all above-mentioned fields, tooth mark interpretations face substantial difficulties in terms of over expectations, requirements for precise and positive individual identification, but at the same time it is subjected to extreme criticism as being subjective, controversial, inconclusive, or at best, having the issues with equifinality. In forensics, human tooth mark analysis is considered as one of the most complicated and demanding parts where the individuality of human teeth and their position allows the forensics to get to a “strong” opinion of association in cases of identification. Tooth marks are identified by their shape and size and described as having an elliptical or oval pattern containing tooth and arch marks that can be matched against the dentition and dental impressions (Reddy et al., 2011; Reesu and Brown, 2016). Within the anthropological and archaeological context tooth marks found on various objects are primarily analyzed in terms of contrasting the marks on the artifacts with those formed by identified causes on contemporary bones. It is usually performed using the same techniques employed in contemporary forensics and dental science research and at the same time ruling out of other possible etiological factors that can inflict similar bone surface alterations, for example, biting or nibbling by other

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predators or rodents, and scratches made by tools during excavation or preparation (Potts and Shipman, 1981).

Analysis of the possibilities of simulating the way in which human teeth may leave visible tooth marks requires in depth analysis of the interfering structures, namely the enamel and the surface of the bone, as well the forces which mastication forces are capable of generating (Wilson et al., 1977; Yuen, 1997; Spears and Macho, 1998; Mahoney et al., 2000; Wang et al., 2006; Zhou and Hsiung, 2007; Fonseca et al., 2008; Constantino et al., 2010; Lin and Xu, 2010; Padmanabhan et al., 2010; Hayashi-Sakai et al., 2012; Le Luyer et al., 2014; Galo et al., 2015;). Masticatory efficacy is described as the competence of compressing foodstuff among the upper and lower teeth and handling the resultant fragments in order to form a final food bolus ready to be swallowed. The effectiveness of mastication is strongly reliant on the oral and facial anatomical structures, the synchronization, as well as the consistency of the foodstuff that is used in the assessment. It has been reported that, under laboratory conditions it is possible to generate the occlusion force in adults up to 750 N on the molars and 250 N on the incisors. It has also been observed that mastication forces generated during regular chewing are significantly smaller, age and foodstuff related (Demes and Creel, 1988; Eng et al., 2013; Révérend et al., 2013; Sghaireen et al., 2014; Stróżyk and Bałchanowski, 2016; Scott and Halcrow, 2017). Human induced marks on bone surface are usually formed when humans chew and bite bones and cut marks, percussion or impact marks or breakage occurs. However, mastication functions, and as a result possibility of leaving tooth marks on various objects is not limited to feeding and drinking behavior.

All tooth marks measurement and morphology evaluation studies share the same objectives of surveying all the associations between real tooth shape and size considering them as representative measures of body size and possibly taxon, and the subsequent tooth mark (Delaney-Rivera et al., 2009). Tooth marks were in depth analyzed and classified according to the methodology of Andrews and Jalvo (1997). Carnivore tooth marks occur as pits, scores or more rarely, punctures (Binford, 2014; Blumenschine, 1995) and contain bowl shaped interiors regularly observed in pits and U-shaped cross sections that are described in scores (Blumenschine, 1995), characteristics that make them distinguishable when compared to cut marks and percussion marks. In last two decades tooth mark classification initially proposed by Selvaggio (1994) and modified by Domínguez-Rodrigo and Piqueras (2003) and Andrés et al. (2012), focusing on two specific signals on bone surface, pits and scores, allow comparisons to be made with numerous experimental and other archaeological samples.

There are reports about the overlap in size of human produced tooth marks with those created by meat-eaters of broadly differing proportions (Delaney-Rivera et al., 2009; Andrés et al., 2012; Saladié et al., 2013). In addition, there are also consistent conclusions that the obtained metrical data are under strong influence of experimental protocol, data acquisition, inclusion criteria, and finally tooth marks measurement techniques. Unavoidably, all contemporary feeding and alterations studies should control the causes and provisional contexts examined (Delaney-Rivera et al., 2009). In order to avoid equifinality in interpretations, comparability between the control and archaeological samples in the agents of infliction must also be demonstrated.

The aims of the present report were to expand the insight of human tooth marks on the surface of bovine bone on the basis of the experimental approach, analyze the influences of the variables controlled in this experiment such as tooth type and masticatory forces applied and finally to improve our factual understanding of these types of bone surface alterations.

2. Material and methods

The current experimental study included chewing by volunteers. All tests were conducted on fresh bovine metatarsal bone from a local slaughterhouse. Cortical bone from between the metatarsal metaphysis and diaphysis were cut down to 3 mm thick specimens with a water-cooled diamond-impregnated low-speed saw (Isomet Low-Speed Saw, Buehler; Lake Bluff, IL, USA). After removal of the marrow with a water jet, the sections were stored at room temperature. All samples were polished before testing using motorized silicon carbide discs of various grit sizes (200, 600 and 1200). The final fragments had average dimensions of 25 mm × 10 mm × 2 mm. The final experimental sample consisted of 37 bones. After the preparation, all specimens were scanned before the experiment on both sides by an electronic microscope (TM3030, Hitachi, Tokyo, Japan) and Zeiss stereomicroscope at magnifications 20 to 50 X.

Five individuals of both sexes (3 men and 2 women), with healthy teeth and no prosthodontics crowns and bridges were select for the chewing experiment. The volunteers were aged between 23 and 45 years. All of them were to some extent related to dentistry (staff of the University of Novi Sad, Dental Clinic of Vojvodina). They were asked to chew and mouth bone specimens and instructed to record the teeth and the intensity level used with particular bone sample (classified into three categories: low, medium and high). So as to constraint all the variables, each individual mouthed and chewed at least three specimens of bone. Throughout the consumption experiment, volunteers wrote down the information on a record card about which teeth they used to chew the bones (classified into four categories: incisors, canines, premolar and molars).

For each individual mark obtained during the experiment the following parameters were recorded, following the methodological principles described in the recent report of our research group (Jovanovic, 2019) as follows:

- Referent image; Tooth mark identification has been accomplished by comparison of the bone sample images before (Fig. 1C) and after (Fig. 1A, Fig. 2B, Fig. 1D, Fig. 1E) the experiment. Bone samples were photographed using SEM (Fig. 2A) or Zeiss stereomicroscope (Fig. 2D and Fig. 2E). SEM evaluation has been performed employing TOPO mode with consistant magnification at 40×, while analyses on Zeiss stereomicroscope were accomplished with varying magnifications from 20× to 50×. All data related to the magnification, scale bar and microscopic mode were obtained for each referent image. Characteristic tooth marks were additionally documented in 2D and 3D Panasis Profiler (Fig. 7, Fig. 10, Fig. 11).
- Specimen numeration; All 37 bone specimens were marked numerically in order to facilitate the tracking of the relationship between the teeth used for chewing the particular sample, intensity applied and mechanism of mark formation.
- Tooth type; With respect to a tooth that was predominantly or exclusively employed in mark formation the following designation was attributed to each mark: maxillary permanent teeth were marked as I, C, P and M, while mandibular permanent teeth were designated as i, c, p and m.
- Intensity level. Five volunteers were included in the experiment under supervision of BP. Participants were directed how to simulate chewing and they all knew the aim of the experiment. Volunteers were instructed to mouth and nibble bone (low intensity level), chew (medium intensity level) and bite as hard as possible (high intensity level).
- Mark dimensions. The length, the breadth and the relationship between the length and the breadth (L/B ratio) of each mark were recorded. Referent images obtained from the SEM and Zeiss microscope were processed and all tooth marks analyses and measurements performed in Gwyddion open source software (Fig. 2B).
- Mark type. All marks having lengths < 3 times their breadths were described as pits. The pit shape was classified into five groups 1) round - a shape that is curved, circular and without sharp angles 2) elliptical - the shape of an ellipse, an elongated circle, stretched into an oval 3) crescent - a thin, curved shape that is thicker in the middle and tapers to thin points at each end as described by

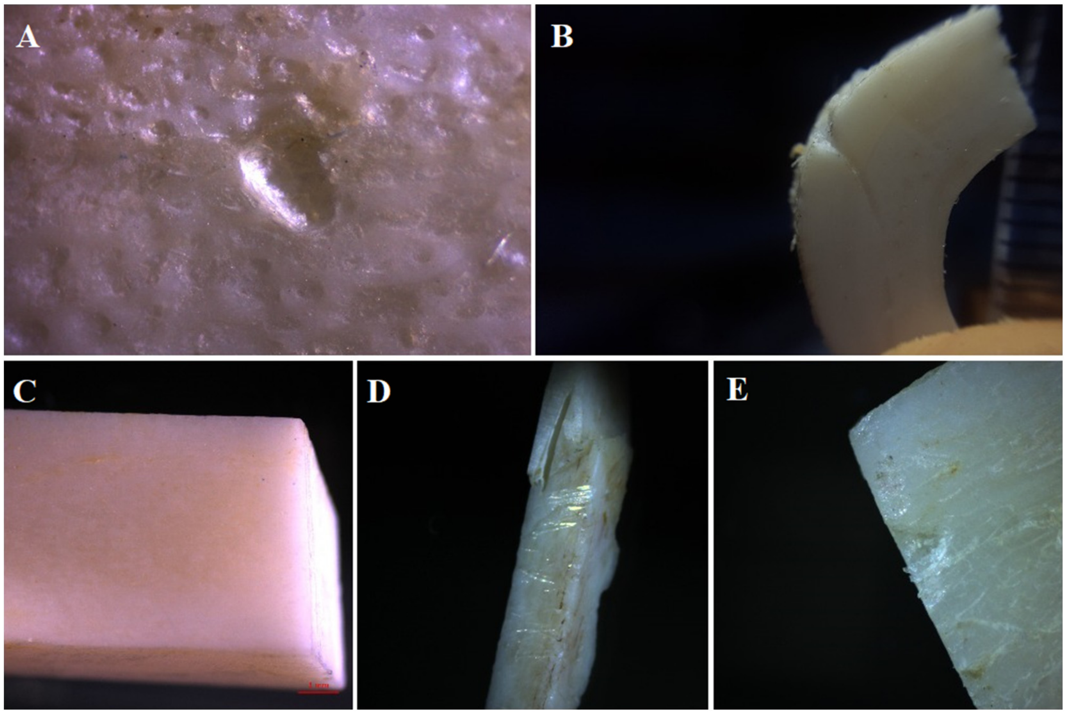

Fig. 1. Bone samples stereomicrosccopic images.

Fernández-Jalvo and Andrews (2011) and Saladié et al. (2013) 4) drop like - shaped like a drop of a thin liquid, having a globular form at the bottom, tapering to a point at the top 5) other- all other, angular and irregular shapes (Fig. 3 A-E). Scores were defined as marks with lengths three times their breadths and longer (Fig. 3 F). When measuring the breadth of a score, the narrowest distance along the linear groove was taken as the representative measurement. Additional characteristics for scores were recorded as follows: location of scores, direction and frequency (multiple or single) of scores on single bones specimen, the presence of branching (branched or unbranched) and shape of each score (straight or curved).

For statistical analysis, basic methods of descriptive and comparative analysis were used.Nominal and categorical variables were presented as number and percent, while continuous variables were presented as mean with standard deviation. Chi square test, and one-way ANOVA with Tukey HSD test were used for two groups' comparison. For statistical analysis, open source statistical program, Jamovi Project (2018), Jamovi (Version 0.9.2.8) retrieved from https://www.jamovi.org was used with significance level set at 0.05.

3. Results

By contrasting the images before and after the experiments a total of 2154 marks had been detected in permanent teeth sample. Table 1 shows permanent tooth marks measurements in relation to tooth type. Observing the results it can be seen that all teeth have been presented with similar amount of tooth marks, suggesting equal distribution as well as similar capability potential of all investigated teeth to generate tooth marks on the bone surface.

Average values for lengths and breadths in all tooth types are distributed in a range < 0,1 mm. When it comes to ratio between major and minor axis (L/B ratio), the values for incisors were significantly higher compared to canines, premolars and molars ($p < 0.05$, Kruskall Wallis test). In addition to that Post Hoc test revealed significant differences in L/B ratio between lowest mean values that were observed in maxillary molars in comparison to premolars and incisors ($p < 0.05$, one way ANOVA test).

Univariate analyses have been carried out (Table 2) with the tooth marks dimensions (L, B and L/B) considered as dependent variables with both intensity levels and tooth types as independent variables. The

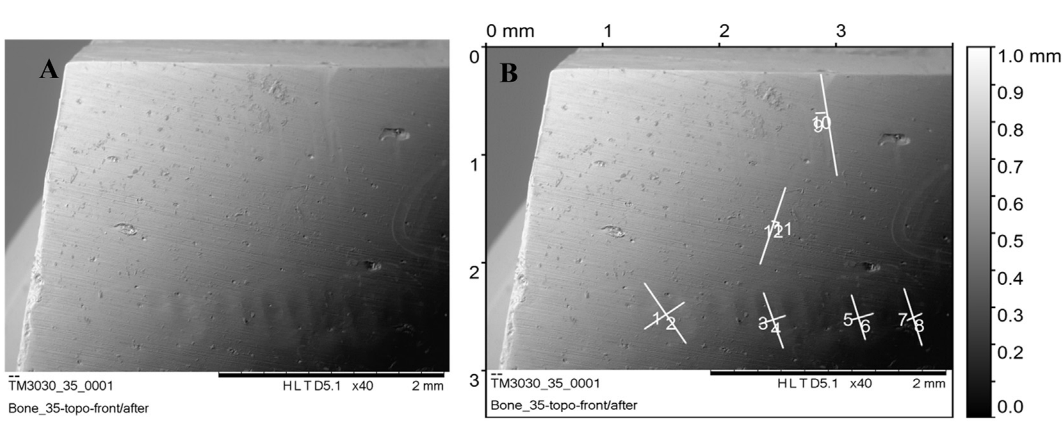

Fig. 2. SEM images: A after the experiment, B with measurements in Gwyddion software.

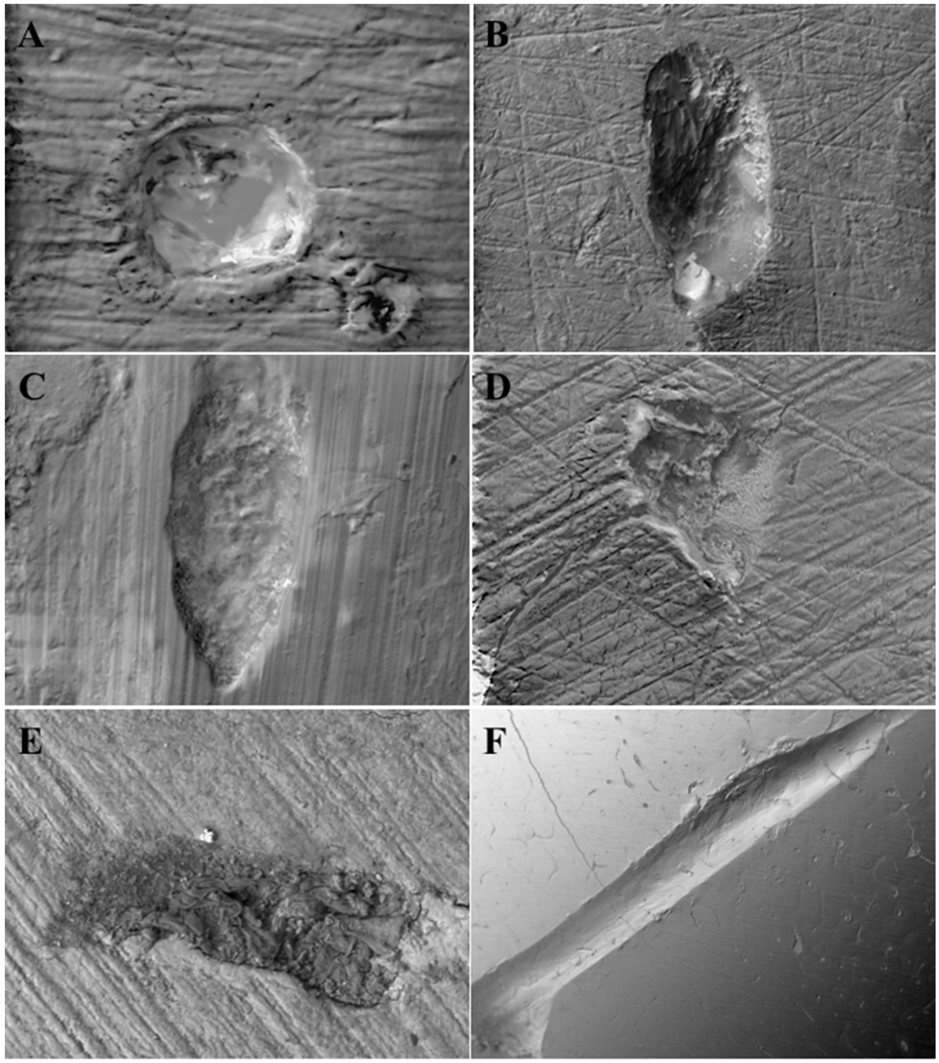

Fig. 3. SEM images of typical TOOTH marks shape: A round, B elliptic, C drop like, D crescent, E other, F score.

results clearly show that intensity level significantly affects ($p < 0,01$) the length and breadth of tooth marks, without significant effect on L/B ratio. The similar results of significant effect on length and breadth and lack of significance regarding L/B ratio was observed when independent variables were analyzed concomitantly. In contrast to that, tooth type solely affected significantly all three investigated dimensional variables ($p < 0.01$). When solely tooth type is being regarded, it is shown that all three investigated dimensional variables ($p < 0.01$) are affected significantly. Analyzing both independent variables concomitantly, results are similar to taking in case only intensity- the effect on length and breadth is significant, while the significance is lacking when L/B ratio is being observed.

Fig. 4 enables comparison of tooth marks dimensions in relation to tooth type in permanent teeth clearly showing the extent of overlap in size.

Correlation analysis revealed statistically significant correlation ($p < 0.01$) between tooth mark lengths, breadths and L/B ratio (Table 3).

Fig. 5 and Table 4 show how intensity level by itself affects the size of investigated variables. It could be observed that mark lengths variate substantially, while at the same time mark breadths together with L/B ratio exhibit more uniform pattern.

The presumption that tooth type (incisors, canines, premolars and molars) have significant effect on the resulting tooth mark dimension has been additionally analyzed by means of comparative and descriptive statistics (Fig. 4, Table 1, Table 5, Table 6). The data show that presented overlap in tooth mark dimension is not simply a coincidental consequence of different teeth sizes used in the experiment. It is also obvious that large sample size, with the methodological approach of describing and recording the hundreds of small tooth marks (with the dimensions as low as 20 μm), resulted in significant statistical overlap, despite the reporting principle either using standard deviation, simply comparing the means or confidence intervals. Regardless the statistical, analytical or descriptive approach employed, the results implicate that permanent teeth types have a significant effect on tooth marks dimensions.

In order to clarify the effect of investigated variables on tooth marks dimensions and mark type distribution additional analyses have been carried out in relation to two types of signals (pits and scores) recorded (Fig. 6, Fig. 8, and Fig. 9).

Fig. 9 shows comparative analysis of the numbers of tooth marks, sorted into previously defined intensity level groups, induced by predominant or exclusive use of one specific tooth for chewing simulation. As it can be seen, crescent, drop like and round shapes are less common in all three pressures applied. Also, it can be seen that more both eliptic marks and marks characterized as others were made by maxillary permanent teeth when low and medium intensities were used. This was not the case only in intensity 1 with premolars. If it is inspected only maximum pressure applied, it can be concluded that there were noticeably more marks done by mandibular permanent teeth, in all

Table 1
Dimensions (length and breadth, and length to breadth ratio, L/B) of tooth marks in relation to permanent tooth type. Data include N (number of obtained tooth marks), mean values, median, standard deviation and minimum and maximum values documented in each sample.

	Tooth type	Mark Length	Mark Breadth	L/B ratio
N	C	295	295	295
	I	291	291	291
	M	365	365	365
	P	265	265	265
	c	308	308	308
	i	178	178	178
	m	174	174	174
	p	269	269	269
Mean	C	0.628	0.324	2.49
	I	0.580	0.305	2.34
	M	0.591	0.331	2.30
	P	0.625	0.274	3.11
	c	0.592	0.251	3.01
	i	0.629	0.257	3.51
	m	0.668	0.328	2.82
	p	0.663	0.287	3.08
Median	C	0.566	0.309	1.75
	I	0.561	0.281	1.68
	M	0.567	0.309	1.68
	P	0.580	0.251	2.15
	c	0.562	0.221	2.26
	i	0.558	0.225	2.27
	m	0.616	0.324	1.90
	p	0.616	0.274	2.11
St. dev.	C	0.282	0.159	2.33
	I	0.308	0.167	1.73
	M	0.238	0.170	1.74
	P	0.297	0.148	3.29
	c	0.297	0.138	2.34
	i	0.359	0.154	3.54
	m	0.295	0.170	2.58
	p	0.320	0.147	3.02
Maximum	C	1.80	0.982	24.3
	I	2.87	0.745	14.2
	M	1.90	0.892	12.4
	P	1.92	0.784	34.1
	c	2.56	0.717	18.2
	i	1.93	0.613	22.7
	m	1.98	0.865	16.5
	p	2.24	0.778	24.0

occasions except when incisors inflicted the tooth mark. The most common tooth mark shape in all three categories is elliptic.

Fig. 9 presents number of observed pits and scores and its relation to both tooth marks shapes and tooth used for chewing simulation. As it was concluded from the Fig. 9, elliptic and other shapes still outnumber the crescent, drop like and round shapes. Also, it can be seen that the number of scores is significant. Comparing pits and scores, the number of elliptical pits is almost as twice as the number of the total scores. When it comes to the level of intensity used to imprint on the bone, there can't be determined the most efficient pressure because the distribution of the number of marks is rather uniform.

4. Discussion

The results from the present investigations provide the data on the ranges and variation of permanent tooth marks or how they can be related to different size of teeth and anticipated forces that were used in mark formation. The findings obtained by contrasting the same images before and after the experiment have been, to the best of authors' knowledge rarely reported in the literature. This study included relatively large sample, of statistical relevance, including the record of the smallest detectable traces on the bone surface which is, also to the best of the authors' knowledge, rather rare report in the literature. In addition we controlled two additional variables, tooth type (incisors, canines, premolars and molars) and intensity levels (low, medium and high) and followed and described the effect of these variables on the tooth marks dimensions, types and characteristics.

Majority of the published reports investigated this topic has been performed on pits, scores, punctures and perforations although almost uniformly based on mean values that may not be as informative as ranges, as suggested by Fernández-Jalvo and Andrews, (2016) and Andrés et al. (2012). The results from the present investigation could not confirm the presumption that ranges of recorded tooth marks can contribute to conclusiveness of the results, because it is evident that the range of bone surface alterations is also dependent of the experimental setup, as well as of numerous additional variables that cannot be easily controlled in the experimental study, and even less controllable and anticipated during interpretation of the archaeological record. On the other hand, the results from the present investigation are completely consistent with the conclusion from abovementioned studies that with respect to the dentition and tooth type, larger meat-eaters are capable of making both miniature and outsized tooth marks, while minor carnivores leave just small tooth marks. Bearing that in mind it has been implied that ranges of tooth marks size, or still more just the dimensions of the five largest marks, could provide a better context to extrapolation and identification of the probable species accountable for specific surface alteration pattern. The results from the present investigation could support the observation that the largest tooth marks recorded on the bone surface are powerful tool in agent identification, but according to the observation from our sample and results, interpretation relying on the particular tooth marks size only carries the risk of misinterpretation. Large tooth marks are informative and indicative, but they are rather rare. In addition, they are always accompanied by numerous smaller scratches, scores and lines, and these multiple marks with specific dimensions, in particular breadth and length to breadth ratio could additionally support the interpretation when referring to bone surface modifications in terms of tooth inflicted alterations.

Despite the fact that tooth marks have been recognizable as appearing in various forms defined by Binford, 2014) as pits, scores, punctures, and furrowing, the present investigation focused on two specific types, pits and score, morphologically and dimensionally defined which are the tooth mark types that are beforehand examined by other research groups (Domínguez-Rodrigo and Piqueras, 2003; Delaney-Rivera et al., 2009, Andrés et al., 2012). Despite the

Table 2
Univariate tests investigating the effect of tooth type and chewing intensity level on tooth marks dimensions in permanent teeth.

	Dependent Variable	Sum of Squares	df	Mean Square	F	p
Intensity Level	Mark Length Real	5.886	4	1.4714	18.634	< 0.001
	Mark Breadth Real	0.733	4	0.1833	8.047	< 0.001
	L/B ratio	24.334	4	6.0835	0.940	0.440
Tooth type	Mark Length Real	2.131	7	0.3044	3.855	< 0.001
	Mark Breadth Real	1.924	7	0.2748	12.063	< 0.001
	L/B ratio	327.898	7	46.8426	7.234	< 0.001
Intensity Level * Tooth type	Mark Length Real	13.994	15	0.9329	11.814	< 0.001
	Mark Breadth Real	3.706	15	0.2470	10.845	< 0.001
	L/B ratio	184.425	15	12.2950	1.899	0.019

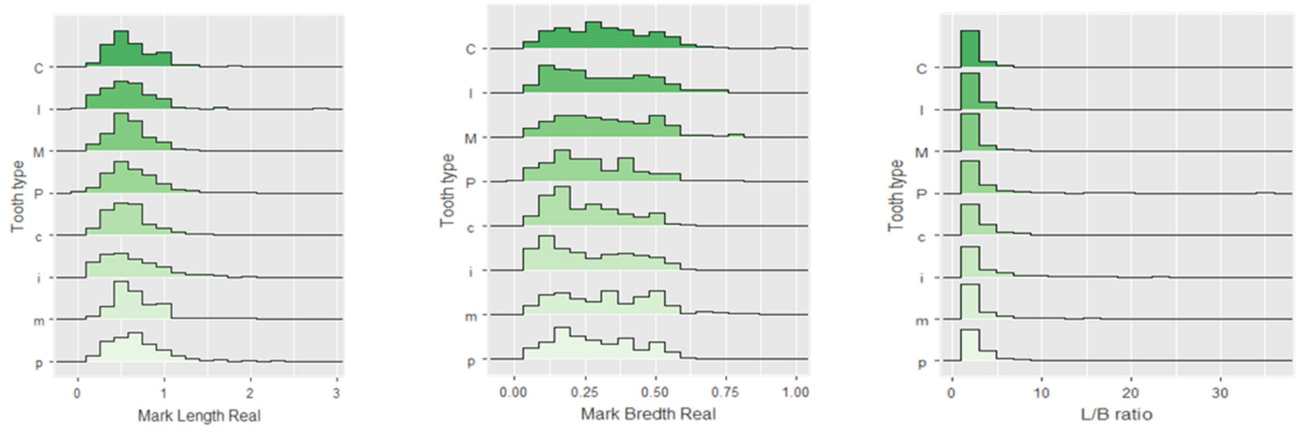

Fig. 4. Mark length, breadth and L/B ratio of primary and permanent teeth.

Table 3
Correlation matrix within the tooth marks dimensions.

		Mark Length Real	Mark Bredth Real	L/B ratio
Mark Length Real	Pearson's r	–	0.337	0.389
	p-value	–	< 0.001	< 0.001
Mark Bredth Real	Pearson's r		–	−0.497
	p-value		–	< 0.001
L/B ratio	Pearson's r			–
	p-value			–

Table 4
Kruskal-Wallis analysis of teeth marks dimensions with respect to low, medium and high intensity level.

	χ^2	Df	P
Mark Length Real	82.89	2	< 0.001
Mark Bredth Real	22.09	2	< 0.001
L/B ratio	5.09	2	0.079

Table 5
Kruskal-Wallis analysis of tooth marks dimensions with respect to low, medium and high intensity level.

	χ^2	Df	P
Mark Length Real	22.0	7	0.003
Mark Bredth Real	69.8	7	< 0.001
L/B ratio	75.2	7	< 0.001

observation of diversity of tooth marks, some recent studies focus on two specific types of tooth marks, pits and scores in order to potentially differentiate carnivore type.

Identification of the species responsible for tooth marks formation is dependent on the assessment of the specific tooth marks dimensions, the characteristic of the item that has been masticated and the distribution of tooth marks at the surface of the bone. Tooth mark record and measurements are sometimes significantly affected by the used microscopic technique, mode or light (Fig. 12). Depending on the imaging or microscopic technique, and the criteria established in the methodology, there is always the risk of under or overestimation, since the obvious tooth marks recorded using one technique become "invisible" in another.

Linear marks in the present investigation are described as scores according the methodology proposed by Selvaggio (1994) and modified by Domínguez-Rodrigo and Piqueras (2003) and Andrés et al. (2012), defined as tooth marks with lengths three times their breadths and longer.

The breadth of recorded tooth marks was as low as 15 μm and the identification of these tiny marks was not difficult because images were compared before and after the experiment using sufficient magnifications. All these discrete tooth marks are included in the analysis, but it should be emphasized here that this approach requires caution in interpretation because they will significantly affect the most commonly used statistical parameters such as mean, standard deviation or confidence interval.

The presence of shallow linear marks, scores, has been identified as one of the most distinctive features related to human mastication. Experimental studies confirmed that these marks are usually formed by human incisors due to their specific incisals' edges morphology and in the literature shallow linear marks with variable lengths and breadths are consistently associated with the incisors biting action. Fernández-Jalvo and Andrews (2016) reported the dimensions of these tooth

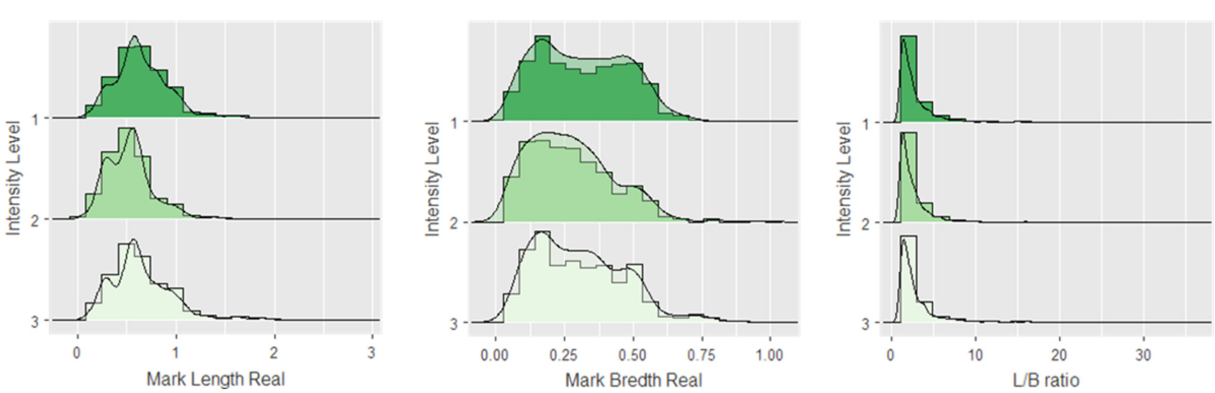

Fig. 5. Intensity level of mark length, breadth and L/B ratio of permanent teeth.

Table 6
Dwass-Steel-Critchlow-Fligner pairwise comparisons between the teeth types.

		Mark length		Mark breadth		L/B ratio	
Tooth type	Tooth type	W1	P1	W2	P2	W3	P3
C	I	−3.2005	0.024	−2.33125	0.099	−0.982	0.488
C	M	−1.8675	0.187	0.34900	0.805	−2.456	0.082
C	P	−0.3322	0.814	−5.27190	< 0.001	4.357	0.002
C	c	−2.6495	0.061	−8.15355	< 0.001	7.321	< 0.001
C	i	−1.4563	0.303	−6.07394	< 0.001	4.793	< 0.001
C	m	1.7908	0.205	0.21494	0.879	1.011	0.475
C	P	1.8221	0.198	−3.74744	0.008	4.753	< 0.001
I	M	1.4136	0.317	2.87389	0.042	−1.510	0.286
I	P	2.7366	0.053	−2.66669	0.059	4.953	< 0.001
I	c	0.6848	0.628	−5.28327	< 0.001	7.812	< 0.001
I	i	1.2937	0.360	−4.26098	0.003	5.395	< 0.001
I	m	4.4754	0.002	2.06548	0.144	1.588	0.262
I	p	4.5860	0.001	−1.12627	0.426	5.347	< 0.001
M	P	1.4097	0.319	−5.70767	< 0.001	6.440	< 0.001
M	c	−0.9247	0.513	−8.77602	< 0.001	9.378	< 0.001
M	i	−0.0190	0.989	−6.71348	< 0.001	6.671	< 0.001
M	m	3.5871	0.011	−0.23172	0.870	2.880	0.042
M	p	3.8147	0.007	−4.15071	0.003	6.852	< 0.001
P	c	−2.2299	0.115	−2.76667	0.050	2.159	0.127
P	i	−1.0614	0.453	−1.95792	0.166	1.161	0.412
P	m	2.0779	0.142	4.46963	0.002	−2.462	0.082
P	p	1.9035	0.178	1.52827	0.280	0.299	0.833
C	i	0.5779	0.683	−0.00190	0.999	−0.605	0.669
C	m	4.1742	0.003	6.80098	< 0.001	−4.429	0.002
C	p	4.2688	0.003	4.46103	0.002	−1.944	0.169
I	m	2.7462	0.052	5.50049	< 0.001	−3.225	0.023
I	p	2.5000	0.077	3.34618	0.018	−0.915	0.518
M	p	−0.2267	0.873	−3.14333	0.026	2.718	0.055

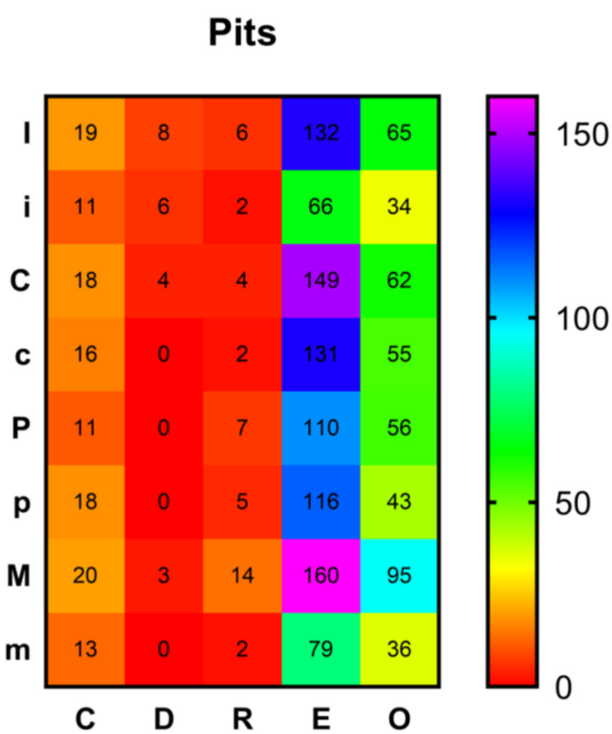

Fig. 6. Heat map representing proportion of different pits types with respect to tooth type.

marks for permanent teeth, stretching between 0,5 and 1.8 mm, and suggested that these linear marks could be still narrower. In the present investigation it has been confirmed in a more consistent and statistically significant sample that the range of tooth mark sizes made by humans is much greater. The breadth of the incisor marks is always narrower compared to the real incisor breadth, which has been completely confirmed in the present investigation.

Linear marks, scores, produced by premolars and molars are rarely reported in the literature. In contrast to that the results from our experiment show that even molars could produce numerous scores.

As suggested by Andrés et al. (2012) the length of tooth marks, particularly the length of linear marks exhibits substantial variation in relation to the dentition type, part of the bone, bone dimensions, bite force and other numerous factors that hardly can be controlled. This observation has been completely confirmed in the present study, where the breadths and L/B ratio where rather constant and resistant to influence of the variables tested in the current experiment. Despite the fact that the agent in our experiment was known, the data obtained are in line with the observation that mark breadth, and maybe length to breadth ratio could possibly indicate the dimensions of the tooth that inflicted the tooth mark more accurately.

The present investigation also confirmed that numerous variables affect the size and geometry of tooth marks, and some of them are without question related to the controlled nature of the chewing experiment and even more controlled in chewing simulation experiment. It has already been reported that tooth marks dimensions are by the rule smaller in archaeological studies (Landt, 2007; Delaney-Rivera et al., 2009; Andrés et al., 2012; Saladié et al., 2013).

The present study predominantly focused on 2D quantitative and qualitative data in tooth marks analysis, and the two dimensional metrics and geometry has been reported for the entire sample consisting of 2154 tooth marks. But, for some samples we tried to tackle the possibility from a metrical and tridimensional perspective using optical prophilometry (Fig. 7, Fig. 10 and Fig. 11). Due to practical reasons and the relatively high number of recorded tooth marks it was impossible to obtained prophilometric 3D images of all tooth marks obtained in the present experiment, but it has been proven that this innovative method to analyze bone surface alterations produced by various agents from a metrical and tridimensional perspective presents a promising alternative (or complementary) technique to conventional microscopic techniques for the tridimensional reconstruction of bone surface

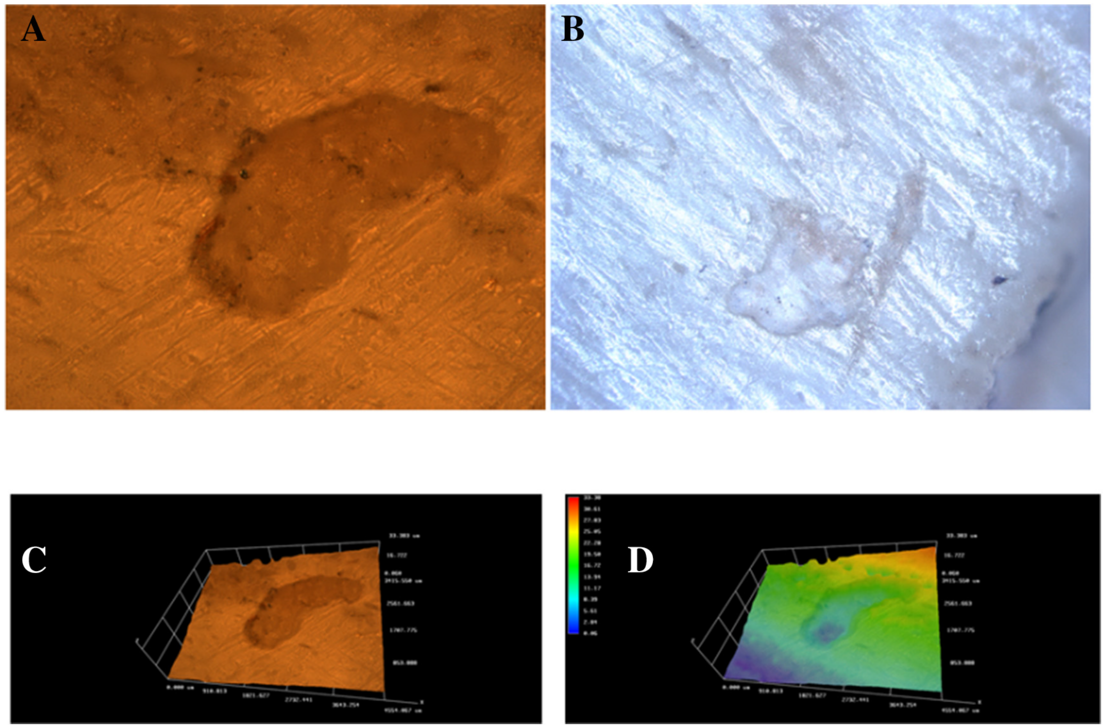

Fig. 7. Panasis profilometer images: A and B 2D preview, C and D 3D preview.

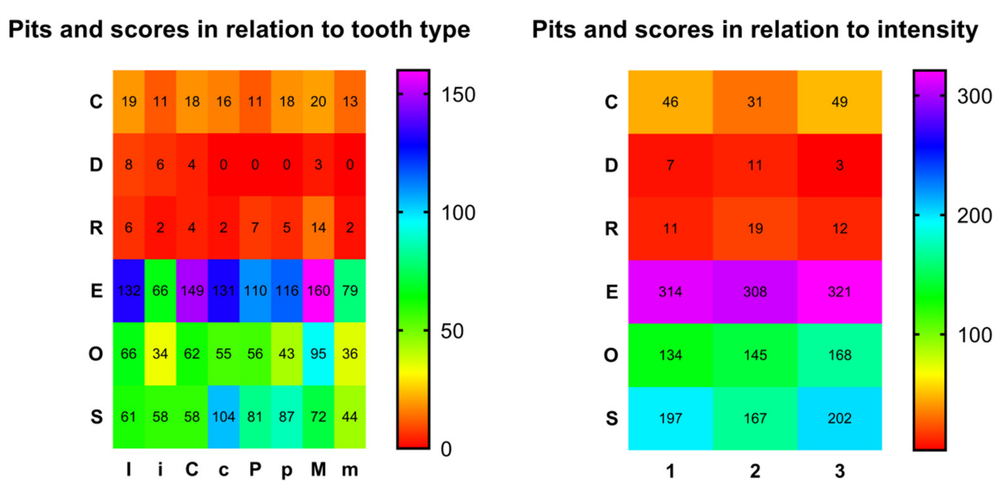

Fig. 8. Heat maps representing proportion of different pits type with respect to tooth type (left) and intensity level (right).

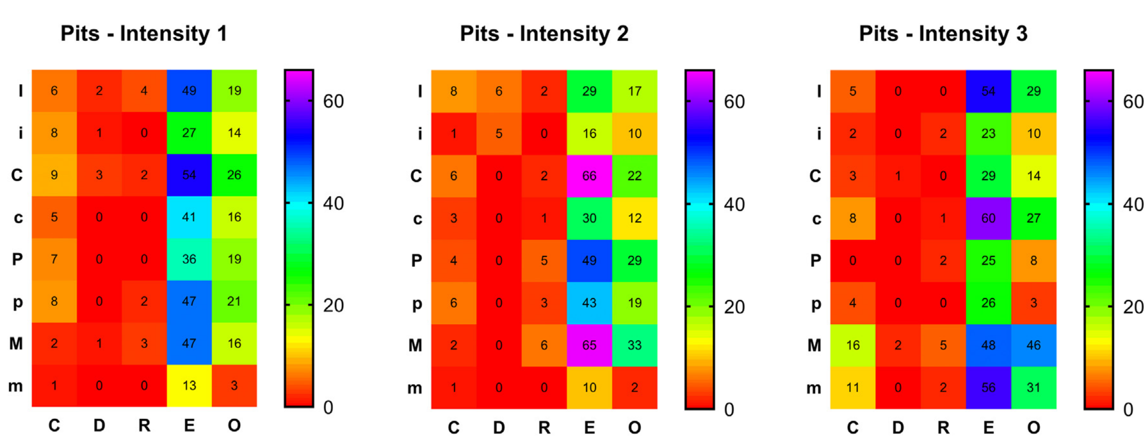

Fig. 9. Heat maps representing proportion of different mark types in all 3intensity levels.

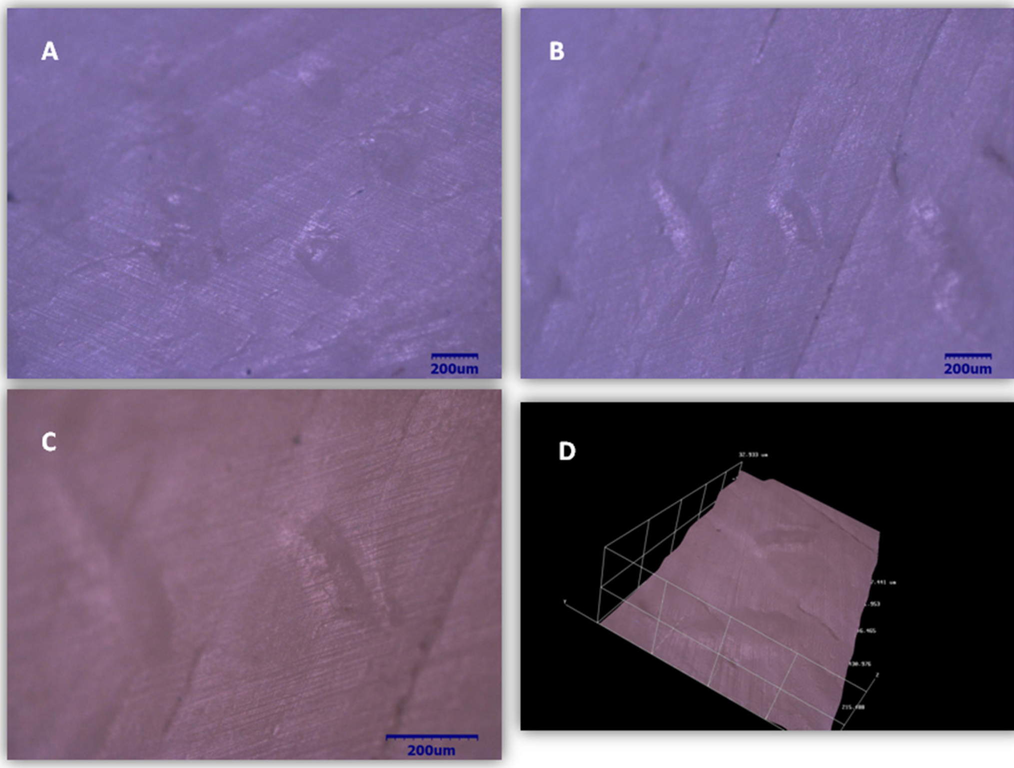

Fig. 10. Bite marks obtained by optical profilometry on bone sample (A, B, C) 2D at magnification 50 × (D) 3D profile.

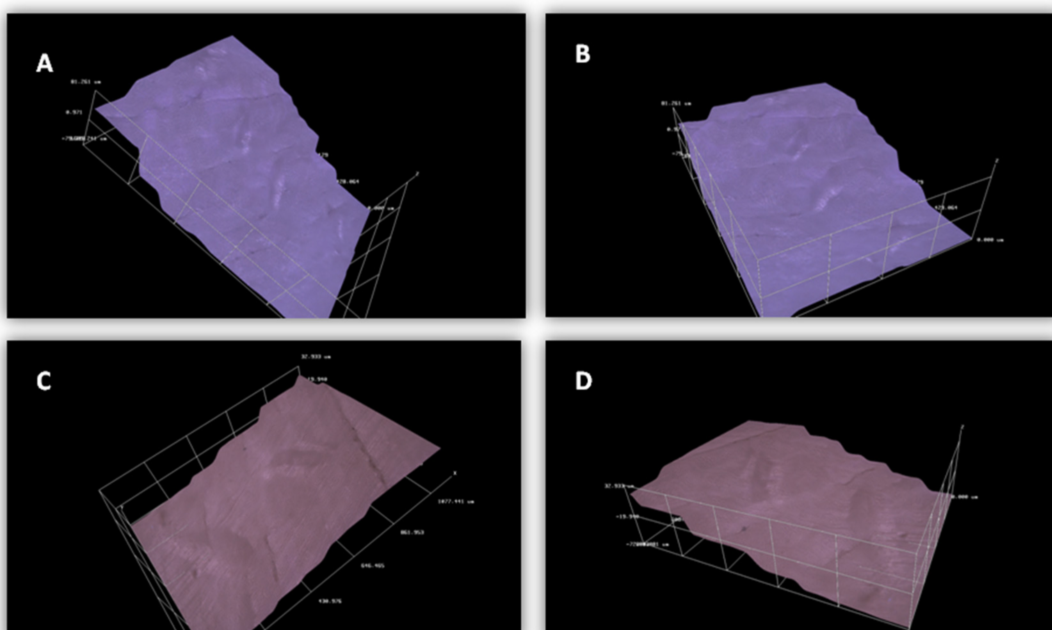

Fig. 11. Bite marks obtained by optical profilometry on bone sample (A,B,C,D) 3D profile.

alterations (González et al., 2015; Aramendi et al., 2017; Arriaza et al., 2017; Yravedra et al., 2017; (Yravedra et al., 2018)

5. Conclusions

Permanent teeth are capable of leaving detectable tooth marks in the range of forces that are far beyond maximal occlusal strengths. There is significant overlap in dimensions between all intensity levels employed, as well as between incisors, canines, premolars and molars. All teeth are capable of inducing all types of investigated tooth marks. When it comes to interpretation potential, it appears that the breadth of tooth marks, and to some extent length to breadth ratio could be related to the size of the tooth accountable for tooth mark formation.

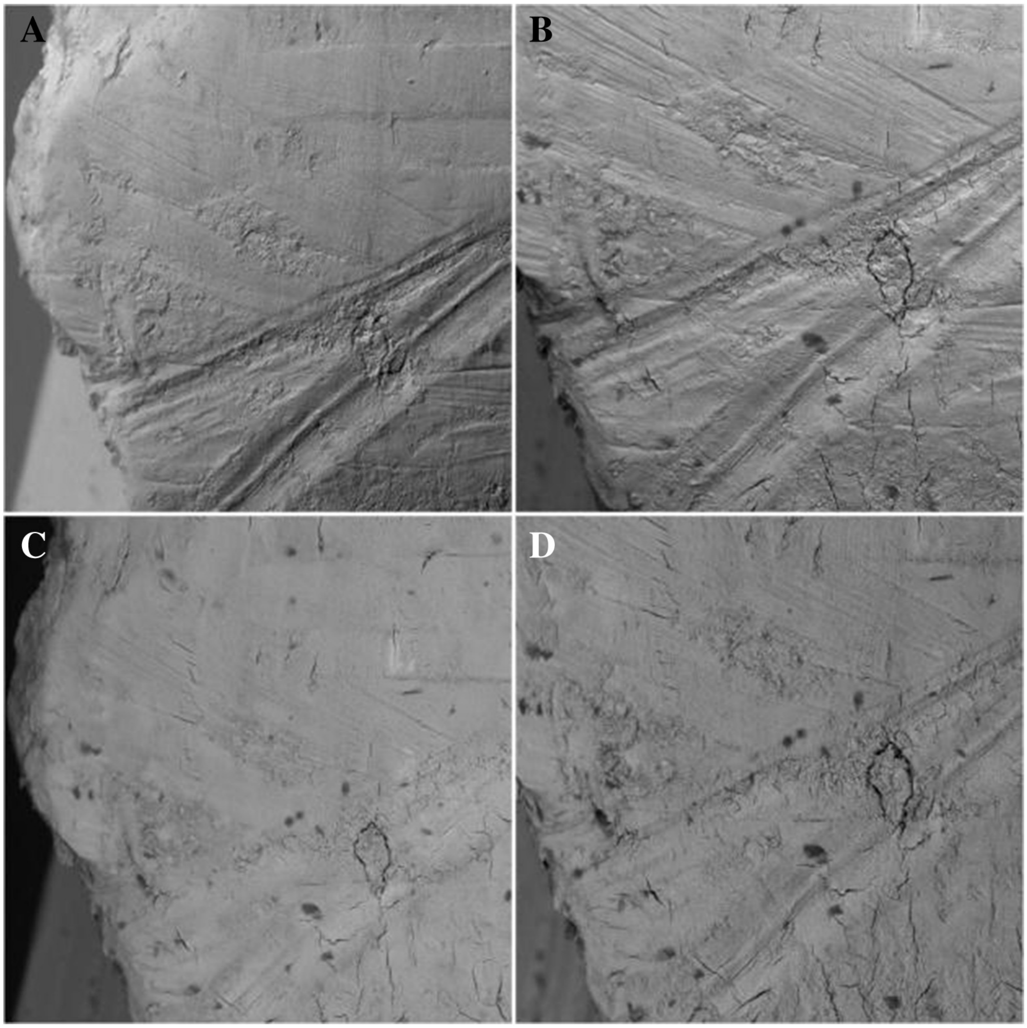

Fig. 12. Variations in TOOTH mark appearance and dimensions in 4 different SEM modes. A topo, B shadow 1, C compo, D shadow 2.

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