RESULTS OF THE USE OF 3D SCANNING IN DENTAL ANTHROPOLOGY STUDIES OF THE MODERN POPULATION

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ABSTRACT:

The article describes results of using a medical intraoral scanner Medit i500 to obtain odontological information in a course of the survey of the modern population in the western regions of the Republic of Tuva within the framework of the complex ethnographic and anthropological expedition of TuvSU-CPI under the leadership of E.V. Aiyzhi. The experience of using this scanner occurred to be very successful. From a technical point of view, the scanner demonstrated high efficiency and productivity due to the high scanning speed. The use of an intraoral scanner opens up wide methodological possibilities in conducting dental anthropology studies: first, the use of digital images for further analysis instead of wax prints, makes it possible to expand the research program by including a number of features of both the lingual and vestibular surfaces of the crowns, and the occlusive one. Secondly, the researcher has the opportunity to accurately fix the sequence and degree of teething of the permanent change, which is very important for determining the correspondence of the "dental" and passport age in children, which ultimately makes it possible to assess the processes of growth and development in the population. Thirdly, it allows us to study in more detail the morphology of the teeth, more accurately assess the severity score of the dental anthropology feature. In addition, thanks to the use of the scanner, we were able to carry out an important methodological study on the analysis of interobserver agreement in the assessment of some dental traits.

1. INTRODUCTION

Dental anthropology (Odontology) is a branch of physical anthropology that deals with the study of the shape and relief of the dental crown, the variability of the human dental system in space and time. Initially, interest in the study of the morphology of the dental crown was focused on paleoanthropological materials. Much later, publications began to appear devoted to the study of the dentition system structures of modern population and its races, but their share was always small.

Russian dental anthropology school, founded by Prof. A.A. Zubov, developed primarily using the research of the modern population. The anthropological diversity of the peoples of the USSR opened up broad prospects for the development of a coherent dental anthropology classification. Large-scale dental anthropology studies of the modern population carried out in the USSR and Russia in the 1970s – 2000s have no analogues in world science. To collect dental anthropology material, Prof. A.A. Zubov developed and successfully introduced a method for obtaining occlusive prints on wax plates as an alternative to the laborious manufacture of plaster casts (Zubov, 1968) (Figure1).

Figure 1. Dental occlusive prints on wax plates.

Possessing a number of advantages, this method also had a significant drawback – it is difficult or impossible to determine the traits of the vestibular and lingual surfaces of the crowns on wax prints. A.A. Zubov proposed to describe them directly "in the field" with the help of a dental mirror. This method of determination, in turn, also has a number of drawbacks, the main of which is "non-reproducibility", i.e. the inability to further check the correctness of the evaluation of the particular trait manifistation. Thus, odontologists have long faced the challenge of finding a more optimal way to obtain data when examining the modern population. It became obvious that obtaining of dental casts, even with the use of modern materials used in dentistry, is not suitable for mass dental anthropology studies. At the same time, in physical anthropology, mainly in paleoanthropological research, 3D scanners are successfully used. But it was found that the scanning accuracy of most scanners designed to obtain 3D copies of large objects, such as the skull, is not enough for teeth. Such capabilities are provided by a specialized intraoral scanner. Such a scanner has been successfully used to obtain digital copies of ancient teeth and jaws (Gaboutchian et al. 2020).

In the last decade, the use of inraoral scanners has been steadily increasing in dental orthodontic practice, but in population anthropological studies of the modern population, this is the first experience of using an intraoral scanner to obtain odontological information. In September-October 2022 we were given the opportunity to use the intraoral scanner in the survey of the modern population in the western regions of the Republic of Tuva within the framework of the complex ethnographic and anthropological expedition of TuvSU-CPI under the leadership of E.V. Aiyzhi (Figure 2).

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Figure 2. Scanning Process.

2. MATERIALS AND METHODS

Within the frames of this field research at least 504 individuals were examined, 331 wax imprints of teeth and 202 full-color scanned images of the upper and lower jaws were obtained (Figure 3). The program of visual dental examination included scoring of the following traits: the presence/absence of diastema (dia UI1–UI1); the presence/absence of crowding (crow) (separately the upper incisors, lower incisors and premolars); the degree of reduction of the upper lateral incisor (red UI2).

Figure 3. Digital image of the upper jaw.

Traits that were described using a dental mirror were also recorded: the severity of the shovel-shaped of the upper incisors (shovel UI1, UI2) and the Carabelli`s cusp on the first upper molar.

Only volunteers were included, and their written approvals were obtained. The scanning was performed with a medical intraoral scanner Medit i500. Our choice of the scanner Medit i500 was not accidental. Its technical characteristics (scanning accuracy of 4.2±0.49 μm; scanning error ±2 μm; scanning area 14x16 mm; light source LED; the possibility of color scanning; weight 287 grams) fully satisfied the requirements of our research.

Our experience of using this scanner was very successful. From a technical point of view, the scanner demonstrated high efficiency and productivity due to the high scanning speed, the ability to start a new scan without waiting for the previous one to be completely saved. Additional advantage: there was no need to use a special powder to cover the surface of the dental crowns prior to observation. All this makes the scanning process relatively comfortable for the individual, particularly in a view that the scanning is performed «in the field», and not in a specially equipped dental office. The undoubted advantage of the scanner is the ability to work offline, it does not require a connection to the Internet.

3. RESULTS AND DISCUSSION

It became obvious that the use of an intraoral scanner, in addition to the purely technical convenience of collecting odontological material, opens up wide methodological possibilities in conducting dental anthropology studies. First, the use of digital images for further analysis instead of wax prints, makes it possible to expand the research program by including a number of features of both the lingual and vestibular surfaces of the crowns, and the occlusive one. Secondly, the researcher has the opportunity to accurately fix the sequence and degree of teething of the permanent change, which is very important for determining the correspondence of the "dental" and passport age in children, which ultimately makes it possible to assess the processes of growth and development in the population. Thirdly, the method of intraoral scanning allows us to study in more detail the morphology of the teeth, more accurately assess the severity score of the dental anthropology feature, without haste (characteristic in the expedition when studying the modern population) to determine the scores in complex, controversial cases (Figure 4–6). Fourth, the resulting series of scans make it possible to create data banks and exchange images.

Figure 4. Anomaly of teething of the upper jaw.

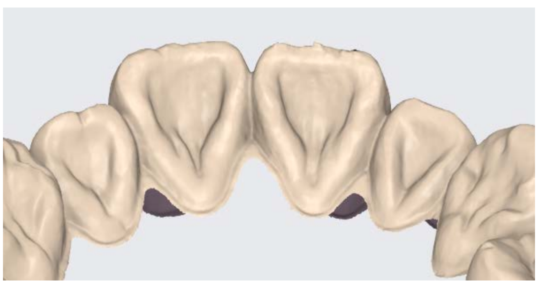

Figure 5. Shoveling upper incisors.

Figure 6. The severity of the Carabelli`s`s Cusp on the first upper molar.

Another promising area of research, which becomes possible thanks to the use of an intraoral scanner, is the search and testing of new traits of the dental crown, including metric ones, obtained specifically on 3D images (Gaboutchian et al., 2017). This trend arose and is developing on the basis of the analysis of the size and shape features of the crowns (mainly molars) of fossil materials, i.e. on craniological series. But in order to understand the nature of an anthropological trait, to assess whether it has a differentiating ability, i.e. how high its taxonomic value is, the trait must be tested on samples representative in number (at least 50 observations) and contrasting anthropologically. Fossil material does not provide such opportunities: craniological series are usually small in volume, contain a large number of individuals of older age cohorts, in which part of the teeth is lost or the enamel of the crowns is erased. It is the presence of a representative database of digital prints obtained during the survey of the modern population that will make it possible to more effectively solve this problem.

An equally significant problem in modern anthropology in general, and in dental anthropology in particular, is the problem of intra- and interobserver agreement in the scoring of descriptive features (Pilloud et al., 2018; Hay et al., 2019). In Russian odontological works, the question of the comparability of data from different researchers was not seriously discussed, since it is believed that the methodology is well developed, and representatives of one methodological school should not have large discrepancies. Episodic connexion seminars, during which A.A. Zubov and his students carried out connexion on working with wax casts, were held only in 1970–1980.

It is on the study of the nature and degree of intra- and interobserver discrepancies in the definition of some dental traits that we would like to dwell in more detail. With the advent of a new method of scoring dental traits using intraoral scanning, it became necessary to assess discrepancies both between the definitions of different researchers and between the definitions of one author obtained in different ways, that is, with the help of a dental mirror, direct visual observation and from a scanned image.

The connexional analysis consisted of several levels of intra- and inter-study comparisons, and included three stages of the experiment to assess the odontological features observed in the expedition and 3D-models. At the first stage of the analysis, the degree of intra-research discrepancies was assessed. Dental traits were evaluated in 186 individuals observed by the same author in the expedition through visual examination and in laboratory conditions on 3D-scans. The results of observations made by A.Kh. Chirkova were analyzed (the results of this stage are not discussed in this article).

The second stage of the experiment was devoted to the analysis of inter-research discrepancies. It consisted in the determination of dental features by two researchers from 3D scans. For inter-author comparisons, all scans obtained in the expedition (202 scans) were viewed independently of each other.

While the first two stages are more aimed at identifying the degree of discrepancies between the authors, then, in the course of the study, the need for an additional, third stage of analysis became apparent, which consisted in identifying the degree of discrepancies obtained as a result of assessing dental traits in the same individual in different ways (through a dental mirror, direct observation and on a digital model). For this part of the experiment, two of the most complex features were examined: the shovel-shaped upper incisors and the Carabelli`s cusp on 26 sculls (a total of 52 observations were obtained) from the storage of the Center for Collective Use "Foundation for Paleoanthropological Materials of the IEA RAS". Thus, a total of three levels of mappings were obtained: 1) comparison of assessments of features made in the expedition and in the laboratory from scanned images by the same researcher; 2) comparison of independent viewing of features from scanned images by two researchers; 3) comparison of their own independent observations of the features carried out by the authors by different methods of fixation.

The analysis was carried out by empirical and statistical methods. Empirical analysis consisted in counting the frequencies of occurrence of each trait. Match percentages were calculated within individual scores and one rating category. In the first case, a coincidence was considered when the author fell into his own definition of the score or a definition made by another author[1]. In the second case, it was important to fall into the category of assessing the presence of the trait. The statistical part of the analysis consisted in calculating the coefficient of conjugation (chi-squared) to obtain reliable discrepancies between the obtained inter-author comparisons[2].

3.1. Results of interobserver comparison (for 3D images).

With independent scoring of features, there is a fairly high frequency of coincidences between authors within the framework of the score assessment of traits and when assessing points within the evaluation categories (Table 1). The lowest frequency of coincidences occurs when determining the shovel-shaped score of the medial incisors, but in this case, the frequency of coincidences is much higher than the values obtained as a result of intra-author comparison. All frequencies of traits viewed by two different authors do not have reliable discrepancies (Table 2).

[1] For example, when assessing shovel-shaped UI, if in one case there was a score of "1", and in the other "0" – then this was taken into account as a "mismatch".

[2] For example, when assessing shovel-shaped UI, if in one case there was a score of "1", and in the other "0" – then this was taken into account as a "coincidence". If in the second case the point "2" was put instead of "0", then this would already be considered as a "mismatch".

traits	% of matches (within one point)	% of matches (within the evaluation category)
dia UI1–UI1	95,6% (n=87)	95,6% (n=87)
crow UI2	95,6% (n=87)	95,6% (n=87)
red [2+3] UI2	95,6% (n=87)	97,8% (n=89)
shovel UI1 [2+3]	64,8% (n=59)	85,7% (n=78)
shovel UI2 [2+3]	71,4% (n=65)	85,7% (n=78)
Carabelli`s cusp [∑2–5]	83,5% (n=76)	92,3% (n=91)

Table 1. Results of the interobserver comparison: mean agreement rates between observers categorized by trait in the evaluation of points and rating categories.

		AC	NL	χ^{2}*
dia UI1–UI1	N	86	85	p= ,3173
	n	3	1	
	%	**3,5**	**1,2**	
crow UI2	N	88	86	p= ,5392
	n	6	4	
	%	**6,8**	**4,7**	
red [2+3] UI2	N	90	88	p= ,9872
	n	1	1	
	%	**1,1**	**1,1**	
shovel UI1 [2+3]	N	78	78	p= ,1495
	n	35	44	
	%	**44,9**	**56,4**	
shovel UI2 [2+3]	N	81	83	p= ,4804
	n	49	47	
	%	**60,5**	**56,6**	
Carabelli`s cusp [∑2–5]	N	74	72	p= ,3006
	n	17	22	
	%	**23,0**	**30,6**	

Table 2. Results of interobserver comparison: frequency divergence.

3.2. The results of a comparison of independent observations of dental traits by different methods of scoring.

In both researchers, the largest discrepancies were recorded when comparing the frequencies obtained from the results of observation with a dental mirror and from 3D scans (Table 3). According to the results of the study, it turned out that one of the authors recorded a natural increase in the frequency of shovel-shaped upper incisors observed from the scanned images (Table 4).

Probably, the option of reducing and approximating the image on the scan can affect the perception of the severity of the feature at the individual level. But the question concerning the peculiarities of the perception by the human eye of certain morphological features in scanned images still needs to be discussed and more thoroughly studied with a sufficient series of relevant experiments.

It should be added that in some cases, the scans did not reveal the shovel-shaped upper incisors, but when directly observing this feature on the skull, two researchers concluded that the sign of shovel-shape is present. So, the initial fears that morphological structures would be *systematically* perceived more prominently on 3D-scans were not confirmed.

The second author also found regular discrepancies, recorded when comparing the frequencies determined with and without a dental mirror. It turned out that the frequencies obtained in the first method of determining the feature are much lower than the frequencies recorded by direct observation.

It follows that the understated frequencies of the shovel-shaped upper incisors, recorded with the help of a dental mirror, which were obtained in the first stage of the study of intra-observer comparisons, were underestimated by the author "artificially". Most likely, the factor of inexperience of the researcher played a role here, which should also be taken into account during the analysis of the results obtained.

In addition to all the identified problems of intra- and interobserver discrepancies listed above, we found another serious problem associated with scoring shovel-shaped upper incisors. Despite the fact that in the methodological manual of A.A. Zubov (Zubov, 1968) published, developed on the basis of the scale of A. Grdlicka (Hrdlicka, 1920), a four-point system for determining the shovel-shape upper incisors with a detailed description of each score, there are still great difficulties in fixing this feature. Moreover, difficulties begin to arise from the discrepancy between the verbal description of the scheme and the illustration given for it (Zubov, 2006) (Figure 7). Also, practicing odontologists have long known the difficulties of distinguishing between points 1 and 2, which can be caused by the peculiarities of the morphology of the lingual surface (Figure 8).

And quite often we have to deal with intermediate options that do not find an exact match in the scale presented. Of course, if we see variants with clearly developed ridges or their complete absence, then, as a rule, researchers do not have any questions, and it is the intermediate variants that cause questions. Foreign colleagues also face methodological difficulties associated with the use of dental traits templates. Thus, in one of the studies of foreign colleagues, the experience of comparing the frequencies

methods of observation	traits / %	N.A. Leybova			A.Kh. Chirkova		
		shovel UI1 [2+3]	shovel UI2 [2+3]	Carabelli`s cusp [∑2–5]	shovel UI1 [2+3]	shovel UI2 [2+3]	Carabelli`s cusp [∑2–5]
with mirror/ without mirror	within one point	90,4 (n=47)	88,5 (n=46)	80,8 (n=42)	75 (n=39)	75 (n=37)	59,6 (n=31)
	within the evaluation category	92,3 (n=48)	94,23 (n=49)	82,7 (n=43)	86,5 (n=45)	80,8 (n=42)	86,5 (n=45)
without mirror/ scan	within one point	80,8 (n=42)	82,7 (n=43)	82,7 (n=43)	90,4 (n=47)	84,6 (n=44)	75 (n=39)
	within the evaluation category	88,5 (n=46)	88,5 (n=46)	90,4 (n=47)	96,2 (n=50)	90,4 (n=47)	88,5 (n=46)
mirror/ scan	within one point	76,9 (n=40)	75 (n=39)	75 (n=39)	76,9 (n=40)	67,3 (n=35)	51,9 (n=27)
	within the evaluation category	86,5 (n=45)	82,7 (n=43)	78,9 (n=41)	84,6 (n=44)	82,7 (n=43)	84,6 (n=44)

Table 3. Intraobserver matching on the results of scoring dental traits in different ways.

		mirror	without mirror	χ^2*	without mirror	scan	χ^2*	mirror	scan	χ^2*
shovel UI1 [2+3]	N	23	24	p= ,6793	24	22	p= ,4001	23	22	p= ,6677
	n	9	8		8	10		9	10	
	%	39,1	33,3		33,3	45,4		39,1	45,4	
shovel UI2 [2+3]	N	38	38	p= ,4899	38	36	p= ,7782	38	36	p= ,3365
	n	19	22		22	22		19	22	
	%	50	57,9		57,9	61,1		50	61,1	
Carabelli`s cusp [∑2–5]	N	33	31	p= ,0680	31	33	p= ,6542	33	33	p= ,1593
	n	6	12		12	11		6	11	
	%	18,2	38,7		38,7	33,3		18,2	33,3	

Table 4. Assessment of intraobserver matching based on the results of observations of dental traits in different ways (N.A. Leybova)

		mirror	without mirror	χ^2*	without mirror	Scan	χ^2*	mirror	scan	χ^2*
shovel UI1 [2+3]	N	27	24	p= ,1658	24	23	p= ,9243	27	23	p= ,2026
	n	13	7		7	7		13	7	
	%	48,2	29,2		29,2	30,4		48,2	30,4	
shovel UI2 [2+3]	N	40	40	p= ,0647	40	40	p= ,4990	40	40	p= ,2371
	n	29	21		21	24		29	24	
	%	72,5	52,5		52,5	60		72,5	60	
Carabelli`s cusp [∑2–5]	N	32	32	p= ,8064	32	28	p= ,7144	32	28	p= ,8861
	n	12	10		10	10		12	10	
	%	37,5	31,2		31,3	35,7		37,5	35,7	

Table 5. Assessment of intraobserver matching based on the results of observations of dental traits in different ways (A.Kh. Chirkova).

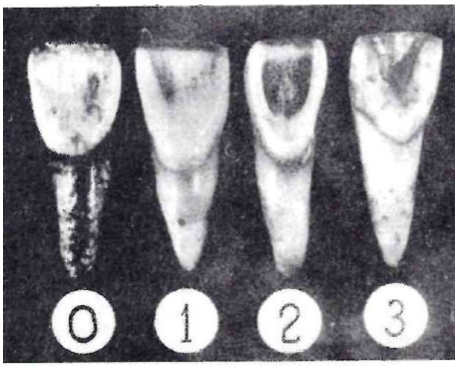

Figure 7. Shoveling scale by A.A. Zubov

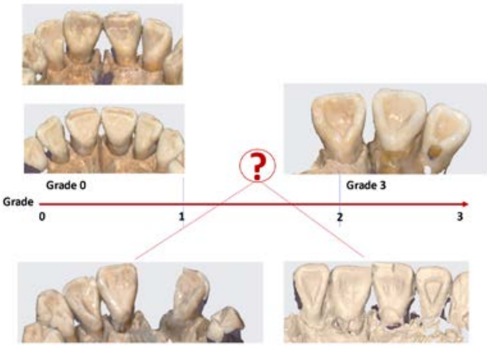

Figure 8. Shoveling on studied sculls

of dental traits assessed by researchers with different experiences is presented (Hay et al., 2019). The degree of comparability between the researchers varied depending on the difficulty of fixing the trait and the authors' experience. Odontological features observed by researchers with different experiences differed in the frequency ranges of coincidences. The highest frequency of coincidences was recorded when observing the shovel-shaped upper incisors, and the lowest – when determining the score of the Carabelli`s tubercle on the first upper molar (Hay et al., 2019). Probably, such results were obtained by foreign colleagues because of the poorly developed scale of the Carabelli`s cusp, and the very detailed and easy-to-use scale of the shovel-shaped upper medial and lateral incisors separately. Also, as we can see, the experience of researchers who observed dental traits is important in such experiments (Pilloud et al., 2018).

4. CONCLUSIONS

Thus, the experience of using the intraoral scanner in dental anthropology studies turned out to be positive and demonstrated its high efficiency and prospects in classical anthropological studies. In particular, thanks to the use of the scanner, we were able to carry out an important methodological study on the analysis of interobserver discrepancies in the assessment of some dental traits and the analysis of intra-observer discrepancies in their determination in different ways.

The method of intraoral scanning allows us to study the morphology of the teeth in more detail, to take a more thorough approach to assessing the dental trait score, and without haste to determine the points in complex, controversial cases.

The assumption of a systematic overestimation of the shovel-shaped upper incisors score when determining a feature from a 3D image was not confirmed, because the discrepancies in the assessment of this feature in the two researchers turned out to be multidirectional. However, in the course of the work, it became obvious that in order to improve the accuracy of assessing the severity of the trait from the scan, it is desirable to use a scanned scale of the feature, which is placed in the same field with the evaluated model.

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REFERENCES

Gaboutchian, A.V., Knyaz, V.A., Leybova, N.A., 2017 Measurements of cuspal slope inclination angles in palaeoanthropological applications. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2/W4, 2017, 2nd International ISPRS Workshop on PSBB, 15–17 May 2017, Moscow, Russia. P. 185–191.

Gaboutchian, A.V., Knyaz, V.A., Novikov, M.M., Vasilyev, S.V., Leybova, N.A., Korost, D.V., Cherebylo, S.A., and Kudaev, A.A., 2020. Automated digital odontometry: measurement data analyses in cases of complicated dental morphology. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLIII-B2-2020, 851–856.

Hay, S., Cirillo, L.E., Vlemincq-Mendieta, T., Kenessey, D., Perash, R. L., Stephanie, J. Cole, Broehl, K.A., Scott, G.R., 2019. Interobserver Agreement in Scoring Dental Morphology using ASUDAS in South Australian Whites. *American Association of Physical Anthropologists 88th Annual Meeting* March 27-30 2019.

Hrdlichka, A., 1920. Shovel-shaped teeth. *American Journal of Physical anthropology.* Vol. 3(4): 187–193.

Pilloud, M.A., Adams, D. M., and Hefner, J. T., 2018. Observer error and its impact on ancestry estimation using dental morphology. *International Journal of Legal Medicine.* 133(3): 949–962.

Zubov, A.A., 1968. Odontology: Methodology of anthropological research, Moscow: Nauka. (Rus.).