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Do it yourself

Morphology, wear and 3D digital surface models: materials and techniques to create high-resolution replicas of teeth

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Introduction

Many anthropological studies are derived from the analysis of dental casts. Dental morphology plays a key role for taxonomy (Wood, 1991), diet and ecological assessments (Swindler, 1976). Tooth wear provides information about food composition (Ungar, 2007), environment, cultural habits (Hinton, 1981), jaw movements (Kay & Hiiemae, 1974), health conditions (King *et al.*, 2005) and determination of age-at-death (Lovejoy, 1985). Today, the study of dentition derived from 3D surface models enables us to obtain more detailed information (Kullmer *et al.*, 2002; Ungar & M'Kirera, 2003) about tooth function and wear. In most cases it is not possible to use the original material directly due to limited access and study-time constraints, and/or methods which cannot be directly applied to the collections, such as analysis through the use of a scanning electron microscope (SEM), which requires an irreversible gold-coating to be added to the specimen. Even if one has taken photographs, micro CT, or 3D surface scans for digital model reconstruction, at the very least it can be advantageous to keep a high quality cast close to hand during the study, as some information can be lost during transition from original to digital format. Replicas of dentition could be created from digital models using rapid prototyping (stereolithography), although the costs remain high and the resolution is only suitable for the analysis of tooth morphology and mesowear. Therefore, it is of great benefit to establish a laboratory with all the principal equipment necessary to produce high-resolution dental replicas for anthropological studies. This contribution provides several guidelines for producing high-quality dental casts.

Procedures for creating high-resolution dental casts

Cleaning

Often the dental surfaces of specimens in anthropological collections are covered by dust and other materials such as glue or varnish.

Consequently, it is important that the dental surfaces are properly cleaned before applying any impression materials used for taking moulds. It is helpful to use a gel (e.g. Syntilor®) with neutral chemical properties to dissolve all remnants of glues or varnishes on the tooth surface, whilst not causing any damage to the specimen (Merceron *et al.*, 2004). Ideally, the dental surface is gently cleaned using cotton swabs soaked with acetone and ethyl alcohol (Ungar, 1996).

Moulding

It is important to consider the aims of the research before deciding upon which technique for casting will be used and which materials are necessary to produce high-quality dental casts (Fig. 1). In fact, the choice of the moulding and casting materials merely depends on the analysis one would like to carry out. Essentially, a mould is the negative impression of an object which has to be filled with casting materials in order to achieve a positive replica. During recent decades many industrial moulding materials have been developed for dentistry with the intent to enhance the cast accuracy, flexibility and biological compatibility whilst also reducing the setting time. Several products are available, with varying hardness, pliability, setting time and accuracy, depending on the purpose of use. As anthropological specimens are often fragmentary and the fossil material fragile, it is absolutely essential to examine the specimen carefully, evaluating the quality of preservation prior to moulding. Enamel surfaces can have fractures and cracks not visible macroscopically, wherein moulding materials could penetrate causing damage from expansion during hardening. Therefore, it is fundamental to observe the tooth crown under a microscope in order to assess the quality of enamel surface. Many anthropological collections are characterized by dental calculus deposits covering the tooth surface. Although detailed techniques to remove dental calculus without damaging the underlying enamel surface are available in the literature (Hillson, 1992), the dental calculus holds precious information (Henry & Piperno, 2008) and its removal could prevent further analysis. Therefore, extreme care should be taken when the specimen possesses dental calculus as it is fragile and could easily be trapped with the enamel surface in the moulding materials during the removal. It is essential to avoid the use of highly rigid impression materials – only the use of moulding materials with a light and soft consistency is recommended.

All the impression materials used in our lab are A-silicone based, hydrophobic polyvinylsiloxane silicones. The President® putty soft (Coltène/Whaledent Inc.) is an impression material with high viscosity and is simple to use. It consists of two components - the catalyst and the base - distinguished by different colors which generate a reaction upon contact. The two materials have to be kneaded until the color becomes uniform. The mixing time is approximately 30 seconds, while the setting time is 180 seconds. Due to low accuracy, this type of impression material is not suitable to replicate very fine details on a tooth surface. A solution to this is to use a dual-phase technique with the addition of the President® light body activated surface (Coltène/Whaledent Inc.), with low viscosity that increases the accuracy including the fine details of the tooth surface. The light body is a silicone-based impression material, composed by two components, the catalyst and the base, which are applied on the primary impression. The two parts must be spread on a flat surface using a spatula with minimal pressure in order to avoid bubble formation, with a mixing time of 30 seconds. In order to facilitate a good cohesion, the primary impression must be dried before applying the light body silicone, with a working time of 120 seconds. Once the second impression material is adhered to the primary impression, the mould must be repositioned on the specimen for approximately two minutes. Another solution is to use the primary impression as a rough approximation, which is later refined by the secondary impression to show the finer details. Although this dual-phase technique generates good results, it requires experience and precision in the synchronization of the working

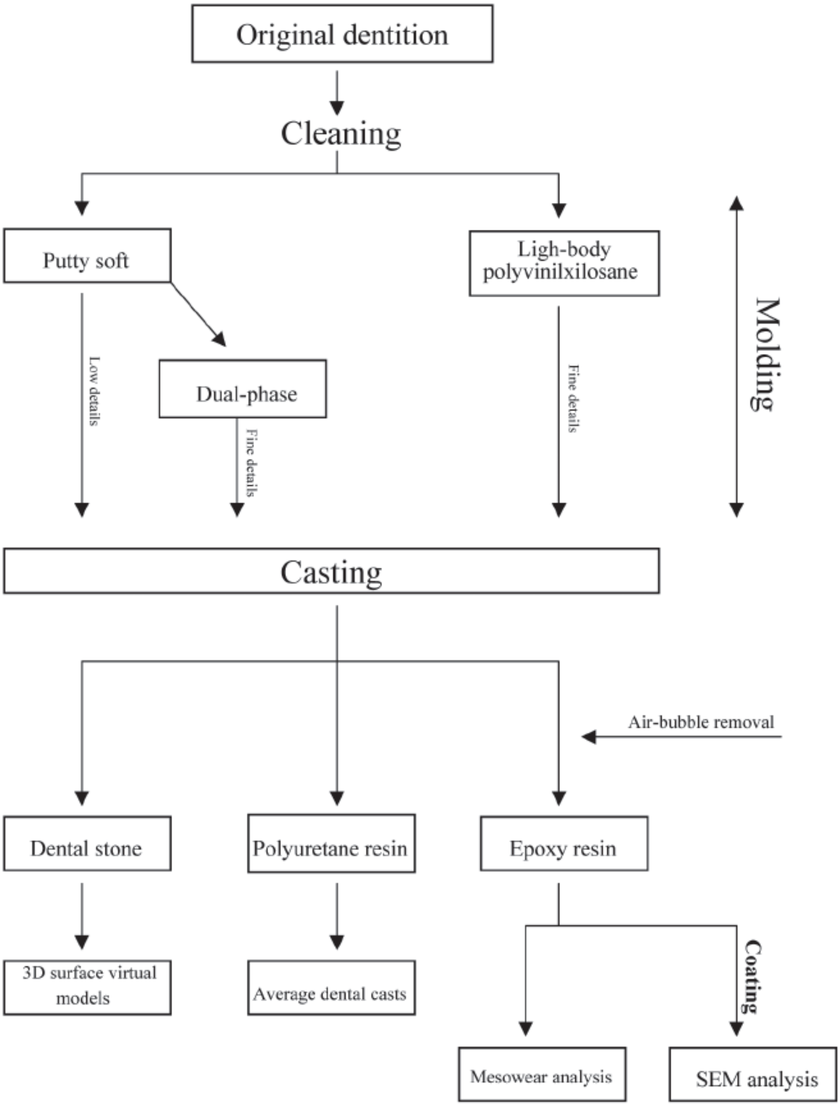

Fig. 1 – ***General diagram wherein the main procedures are illustrated in order to obtain different types of casts suitable for different analysis.***

time between the two phases. A better solution, found throughout the anthropological and dentistry fields, is to apply a monophasic technique, constituted by the light body polyvinylsiloxane silicone (Teaford & Oyen, 1989; Ungar, 1996; Merceron *et al.*, 2004). Similar products from different companies are also available, such as Silagum® light (DMG), Provil® Novo Light C.D.2 (Heraeus Kulzer GmbH) and President® Jet regular/light body (Coltène/Whaledent Inc.). All these products are simple to use. The silicone is sold in cartridges which are inserted in the dispenser gun, with 120-150 seconds of working time (Fig. 2).

The two components are automatically mixed via the mixing tip. This technique has the enormous advantage that it allows work on a series of specimens. To avoid the formation of air bubbles, the impression material has to be dispensed slowly, with the mixing tip constantly in contact with the dental surface. It is also important to consider the air humidity and the temperature of the working environment. All these products work well with a temperature between 15-25 C° and approximately 50% relative humidity. At higher temperatures, the impression material becomes sticky, the total setting time is extended, and it becomes difficult to remove the material from the specimen. One possible solution is the cooling of the moulding materials, which will extend the working time without affecting the accuracy or working characteristics (Chee & Donovan, 1992). In order to extend the life-span of the mould, once the first layer is set on the teeth, it is recommended to add an additional layer to increase the thickness of the mould. Generally, between 8 and 10 casts can be produced from each mould, which can then be used for morphological and macrowear analysis. Cast quality however, only remains optimal for SEM observation until the fourth consecutive replica from the original mould, particularly at high SEM magnification levels (Galbany et al., 2006). Care should be taken during casting such as avoiding the use of latex gloves containing sulphur elementals (Kimoto *et al.*, 2005), or hand lotions (Goodwin & Chaney, 1994), which could react with the impression material causing complete polymerization inhibition.

Casting

As a large number of casting materials and techniques are available, in this contribution we will focus on the principal casting equipment

Fig. 2 – ***Moulding the dentition of the original Neanderthal fossil of Le Moustier 1 (Museum für Vor- und Frühgeschichte, Berlin) using a light body polyvinylsiloxane silicone.***
The colour version of this figure is available at the JASs website.

with respect to two different aims, firstly the reconstruction of 3D virtual models through the use of a surface scanning system, and secondly, tooth wear analysis. One of the major problems that occurs during the surface scanning of teeth is the reflection and transparency of the enamel. Both, white-light and laser surface scanning systems are not able to accurately measure the surface information directly from the original tooth crown. To solve this problem it is possible to coat the dental surface with talcum powder or ammonium chloride fog lending the surface an opaque appearance. However, the small particles of these substances can fill pits, grooves and striations of the dental surface, which may be difficult to remove, and prevents microwear analysis. The best solution is to employ particular casting materials specifically suited for surface scanning. We use a special dental stone (Everest Rock, KaVo) (Fig. 3b) possessing non-reflective properties, optimized for light scanning. The resolution of the dental stone cast is suitable for digital 3D surface models with increased quality for morphological analysis (Fig. 3d). The dental stone is easy to process, has relatively low costs, and cures in approximately 30 minutes.

For dental microwear analysis, the casting materials most commonly used is various epoxy resins (Teaford & Oyen, 1989; Hillson, 1992) such as Araldite® 2020 (Vantico Ltd.), EPO-TEK® 301 (Epoxy Technology, Inc.) and LARIT (Lange und Ritter, GmbH), which produce highly accurate replicas. In our laboratory we use the epoxy resin LARIT L-160, and the hardener LARIT 502 (Lange und Ritter, GmbH). These casting materials are transparent, with low viscosity and a relatively lengthy total curing time. At room temperature it cures fully within 24 hours, however it is possible to reduce the setting time by placing the epoxy resin in temperatures higher than 60° C (cure time between 1-2 hours). Another type of resin used is polyurethane, capable of detail reproduction comparable to the epoxy materials (Derrien & Le Menn, 1995) and suitable for SEM observations. A different polyurethane resin with less accuracy, such as NEUKADUR® PU 172 and the hardener NEUKADUR® H 118 V (Altropol Kunststoff, GmbH), can be employed for analysis at low and medium resolution. This type of polyurethane has many advantages making it an interesting alternative. The setting time is only about ten minutes, it is simple to use and also comparatively cheap.

One aspect which has not been considered yet is the formation of air bubbles during the casting process. A low cost solution (see Tab. 1) is provided by an opto-electronically controlled mini shaker with variable speed, such as the model Vibrax VXR (IKA® WERKE GmbH and CO.KG). It is important to set the filled moulds well by lining the surface of the electronic shaker platform with plasticine prior to starting the machine to help stabilize the object. Another way of reducing bubble development is to employ a vacuum chamber that works at low pressure – the air contained inside the closed chamber is removed via a pump. There are several vacuum chambers available with different sizes, costs and characteristics to meet different demands. Our laboratory is equipped with a Vacutherm R8 (Heraeus Kulzer GmbH) drying oven which can be used to remove air bubbles but also to increase the temperature in order to reduce the curing time. Equipping a lab to produce dental casts does not require a lot of space, and a desk of 1.5 meters in length would be sufficient.

Coating

Since the epoxy resin is transparent, in order to analyse the dental replicas it is necessary to colour the resin prior to casting. Epoxy resins can be coloured using a wide variety of pigments (in the form of powders, slurries or pastes) and dyes, both organic and inorganic (Boyle *et al.*, 2001). Before using colouring products it is important to consider their compatibility with the epoxy materials. The epoxy resin companies provide colouring materials suitable for epoxy casting resins. The most commonly used products are colouring pastes added to the resin and blended to produce a homogeneous mix. Colouring pastes are pre-dispersed pigments making them preferable to powders where the dispersion can be difficult without the proper equipment (Boyle et al., 2001). It is recommended to use opaque, non translucent colours, which are ideal for analysis under the miscroscope. For analysis of images produced by SEM, the dental replicas must be coated prior to analysis with a material having conductive properties such as gold or graphite (Grine, 1986; Hillson, 1992; Pérez-Pérez *et al.,* 1999; Smith *et al.*, 2002). Therefore, it is important to consider the necessity to equip the laboratory with a sputter coater. There are many products available on the market – the K550X Sputter Coater (Quorum Emitech) (Martinez-Maza *et al.*, 2006) for example. The coating time is determined by the sputter coater characteristics and by the thickness of the coating layer.

Conclusions and Suggestions

Setting up a laboratory to produce dental replicas does not require a lot of space or costs. It is important to accurately evaluate which specific type of analysis one wants to carry out before starting with moulds and casts. In this contribution a general overview on a few techniques and materials utilized in the anthropological field was presented. We suggest to the reader to test the material before making the appropriate choice, as some of these products are more affordable than others. Finally, the quality of the moulds and casts not only depend on the type of material used, it is also a matter of practice.

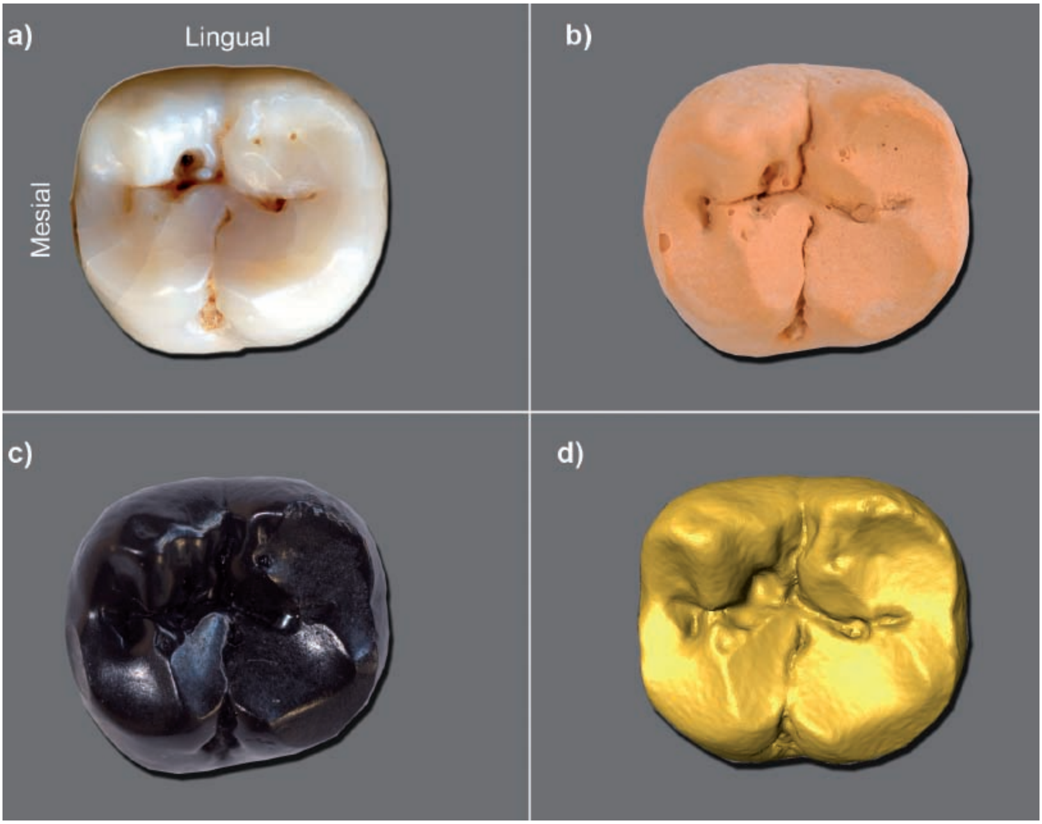

Fig. 3 – a) ***Original lower molar;*** **b)** ***dental stone cast;*** **c)** ***epoxy resin cast;*** **d)** ***3D virtual model obtained from the surface scanning of the dental stone cast.***
The colour version of this figure is available at the JASs website.

Table 1 – *List of the necessary equipment and the estimated costs.*

Item	Description	Estimated cost (€)
Moulding material	Putty soft (2x300 ml)	70
	Light body-surface activated	45
	polyvinylsiloxane/light body	30-45
	dispenser	45
	mixing tips (48)	25
	intraoral tips (96)	25
Casting material	Everest Rock gypsum (5 kg)	35
	Epoxy resin (200g)	100
	Polyurethane resin (5 kg)	40
Miscellaneous	Optoelectronically controlled mini shaker	800-900
	Vacuum chambers	500-6000
	Sputter coater	4000-10000

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References

Boyle M.A., Martin C.I. & Neuner J.D. 2001. Epoxy Resins. In D.B. Miracle & S.L. Donaldson (eds): *ASM Handbook Composites Volume* 21, pp. 78-89. ASM International, Material Park, Ohio.

Chee W.W.L. & Donovan T.E. 1992. Polyvinil siloxane impression materials: A review of properties and techniques. *J. Prosthet. Dent.*, 68: 728-732.

Derrien G. & Le Menn G. 1995. Evaluation of detail reproduction for three die materials by using scanning electron microscopy and two-dimensional profilometry. *J. Prosthet. Dent.*, 74: 569-574.

Galbany J., Estebaranz F., Martínez L.M., Romero A., De Juan J., Turbón D. & Pérez-Pérez A. 2006. Comparative analysis of dental enamel polyvinylsiloxane impression and polyurethane casting methods for SEM research. *Microsc. Res. Tech.*, 69: 246-52.

Goodwin M.B. & Chaney D.S. 1994. Molding and casting: techniques and materials. In: P. Leiggi & P. May (eds): *Vertebrate Paleontological Techniques,* pp. 235-271. Cambridge University Press, Cambridge.

Grine F.E. 1986. Dental evidence for dietary differences in Australopithecus and Paranthropus. *J. Hum. Evol.*, 15: 783-822.

Henry G.A. & Piperno D., 2008. Plants in Neanderthal Diet: Plant Microfossil Evidence From the Dental Calculus of Shanidar III. PaleoAntrhopology 2008, Annual Meeting Abstracts: A11-A12.

Hillson S.W. 1992. Impression and Replica Methods for Studying Hypoplasia and Perikymata on Human Tooth Crown Surfaces from Archaeological Sites. *Int. J. Osteoarch.*, 2: 65-78.

Hinton R.J. 1981. Form and patterning of anterior tooth wear among aboriginal human groups. *Am. J. Phys. Anthropol.*, 54: 555-564.

Kay R.F. & Hiiemae K.M. 1974. Jaw movement and tooth use in recent and fossil primates. *Am. J. Phys. Anthropol.*, 40: 227-256.

Kimoto K., Tanaka K., Toyoda M. & Ochiai K.T. 2005. Indirect latex glove contamination and its inhibitory effect on vinyl polysiloxane polymerization. *J. Prosthet. Dent.,* 93: 433-438.

King T., Humphrey L.T. & Hillson S. 2005. Linear Enamel Hypoplasias as Indicators of Systemic Physiological Stress: Evidence From Two Known Age-at-Death and Sex Populations From Postmedieval London. *Am. J. Phys. Anthropol.*, 128: 547–559.

Kullmer O., Huck M., Engel K., Schrenk F. & Bromage T. 2002. Hominid Tooth Pattern Database (HOTPAD) derived from optical 3D topometry. In: Mafart B., Delingette H. (ed), *Three-Dimensional Imaging in Paleoanthropology and Prehistoric Archaeology*. Liege, Acts of the XIVth UISPP Congress, BAR Int. Ser.1049, pp. 71-82.

Lovejoy C.O. 1985. Dental wear in the Libben population: its functional pattern and role in the determination of adult skeletal age at death. *Am. J. Phys. Anthropol.*, 68: 47-56.

Martinez-Maza C., García-Vargas S. & Rosas A. 2006. Bone Paleohistology and Human Evolution. *J. Anthropol. Sci.,* 84:33-52.

Merceron G., Blondel C., Brunet M., Sen S., Solounias N., Viriot L. & Heintz E. 2004. The Late Miocene paleoenvironment of Afghanistan as inferred from dental microwear in artiodactyls. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 207: 143-163.

Pérez-Pérez A., Bermúdez De Castro J.M. & Arsuaga J.L. 1999. Nonocclusal dental microwear analysis of 300,000-year-old Homo heilderbergensis Teeth from Sima de los Huesos (Sierra de Atapuerca, Spain). *Am. J. Phys. Anthropol.*, 108: 433-457.

Smith T.M., Martin L.B. & Leakey M.G. 2002. Enamel thickness, microstructure and development in Afropithecus turkanensis. *J. Hum. Evol.*, 44: 283-306.

Swindler D.R. 1976. *Dentition of Living Primates.* Academic Press, New York.

Teaford M.F. & Oyen O.J. 1989. Live primates and dental replication: New problems and new techniques. *Am. J. Phys. Anthropol.*, 80: 73-81.

Wood B.A. 1991. *Koobi Fora Research Project, Volume 4: Hominid Cranial Remains.* Clarendon Press, Oxford.

Ungar P.S. 1996. Dental microwear of European Miocene catarrhines: evidence for diets and tooth use. *J. Hum. Evol.,* 31: 335-366.

Ungar P.S. & M'Kirera F. 2003. A solution to the worn tooth conundrum in primate functional anatomy. *Proc. Natl. Acad. Sci. USA*, 100: 3874-3877.

Ungar P.S. 2007. *Evolution of the Human Diet*. Oxford University Press, New York.

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