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Measurement errors in 3D models used in osteometric data research with freeware: a test using skulls of the Algerian hedgehog (*Atelerix algirus*)

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Abstract

The use of 3D models is becoming commonplace in both scientific investigation and in more general educational activities; nevertheless, methodologies and their associated software are both relatively expensive to use. As well, measurements of 3D models must be comparable to that of originals if they are to be used in scientific research. The aim of this study was to determine the degree of error in measurements taken from 3D models and from the original skulls of Algerian hedgehogs (*Atelerix algirus)* using a freeware program. To do so, we measured the repeatability (ri) of four biometric measurements of 14 skulls of this North-African hedgehog species.

We generated 3D models of skulls of 14 specimens from the collection in Barcelona Natural History Museum using the NextEngine scanner and free software and a low-price computer. The same observer measured each variable twice for each skull using three different methodologies: (i) measurement of the original; (ii) measurement of 3D models projected onto a screen with *no* zoom (i.e. replicating the original skull size) and (iii) measurement of 3D models projected onto a screen *with* the maximum possible zoom. The repeatability within each method (INTRAMETHOD) and between methods (INTERMETHOD: original *vs*. screen No-zoom; original *vs*. screen zoom) were tested. The methods *per se* were either very highly repeatable (ri > 90%) or very repeatable (ri > 0.75), the only exception being a difference in the length of the median palatine on the screen with no zoom (ri: 0.64) due to a single outlier.

When comparing digital models, our data suggest that measurements taken from skull borders are more reliable than those in which measurements are taken from sutures due to the differences in the contrast obtained in the finish of the 3D models. Thus, the contrast in 3D models needs to be improved, possibly by means of digital treatment. Our results suggest that the 3D models obtained using the scanner NextEngine and edited using open-access freeware (Meshlab®) are comparable with original specimens and so are a good alternative for museums with fewer financial resources.

Key words

3D models, repeatability, *Atelerix algirus*, craniometric measurements, zoological collections, museum.

Introduction

The use of new technology in museums is nowadays essential since it represents an important modernising step forward that can generate reliable scientific data (Godin *et al.*, 2002; White & Folkens, 2005). Nevertheless, given that technology is advancing extremely quickly, it is vital to verify practical applications and test whether or not they can yield the scientific and cultural results expected of them.

The use of technology for generating 3D models can lead to important changes in a museum's work but does also raise questions regarding the desirability in certain cases of substituting original museum specimens with 3D

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models. Nonetheless, the use of such models will bolster museums in their work, improve the conservation and the ability to study especially fragile material, and allow researchers to consult specimens without having to physically visit the museum (Metallo & Rossi, 2011; Kuzminsky *et al*., 2012). New 3D technology allows visitors to appreciate collections via virtual visits, and also enhances the museum's capacity to put delicate material or unique pieces on display by creating 3D models (Metallo & Rossi, 2011). New 3D-printing techniques can generate models at scales that make specimens far more accessible for both scientific investigation and educational use (Rengier *et al*., 2010). In addition, the use of 3D models has been mooted in restoration as a means of capturing information from damaged surfaces; this information can then be used to define restoration protocols that will make specimens more suitable as didactic and educational tools (Martin Lerones *et al.,* 2015). In fact, virtual collections already exist in which various museums display part of their collection as 3D models (e.g. Human Evolution Evidence, 2014).

The modelling of fossils, shells, minerals, bones, statues, entrances to buildings, coins and other types of material opens the door to a wide range of new applications and provides access to museum collections from anywhere on the planet with no risk of damage to specimens (Martini & Ripani, 2009; Aurell & Fortuny, 2010). Lineal, surface and volume measurements, of either the whole model or of just a part, can be obtained straightforwardly (Tocheri, 2009). These types of models can be acquired via a number of different methodologies (Falkingham, 2012), including, habitually, the superposition of photographs, optical scanners (white light or laser), computed tomography or synchrotrons (Tocheri, 2009). Optical scanners generate models of the outer surface of the specimen, while computerized photography and synchrotrons enable the internal structures of a piece to be captured. The difference between these methods resides in the degree of precision to which the model replicates the original; however, it is important not to lose sight of the fact that 3D models are only ever an approximate representation of an original specimen (Tocheri, 2009).

For 3D models to be useful in research it is essential to guarantee that the modelling process generates a faithful representation of the form and volume of the specimen, as well as of its measurements, scale and proportions (Kuzminsky *et al*., 2012). In some cases, representations of colour and details of textures, sutures, cavities and small bone structures are also required, although to date the replication of colour and textures are challenges that 3D modelling has not yet fully resolved (Slizewski *et al*., 2010). In other fields such as architectural restoration these goals are satisfied by 3D models using mixed techniques (Martin Lerones *et al.,* 2015).

Given the precision with which scientific studies are undertaken, the faithfulness of a 3D model with respect to the original specimen is of utmost importance, above all when the element to be measured is relatively small. A basic supposition is that the measurements taken from a 3D model will be the same as those taken from the original. Repeatability (ri) is a statistical measurement of the reliability of repeated measurements of a single characteristic of *the same* specimen, and is used to quantify statistically the consistency of equivalent measurements of a particular object (Senar, 1999; Quesada & Senar, 2006). Additionally, it can be used as an indicator of the consistency *between* methods (Figuerola *et al*., 2000; Quesada & Senar, 2006; Sholts *et al*., 2010). Repeatability values lie in the range 0–1, with the Measurement Error being calculated as 1-ri. Thus, a very high repeatability value (> 0.90) will indicate an inconsequential error in measurement, while a low value suggests that the measurement error should be taken into account and corrected (Lesser & Boag, 1987; Senar, 1999).

Natural history museums generally conserve series of skeletons of numerous living species that are used in disciplines as varied as palaeontology, biology, medicine and education (Wood *et al*., 2011; Stucchi & Figueroa, 2013; Tallman *et al*., 2013). The examination, comparison and measurement of bones enable remains to be identified and biometric studies to be undertaken on specific specimens (White & Folkens, 2005).

In spite of the fact that current scanners are increasingly affordable, the technology they use is often both expensive to run and to obtain if high resolutions are required (Kuzminsky *et al*., 2012). This means that such equipment may be out of the economic reach of some small local museums or museums in countries with less economic potential. Despite their use of algorithms that do not provide such high resolutions as those attained by commercial packages, the use of freeware is a possible alternative for museums with fewer financial resources. However, in biometric studies it is essential to ensure that the data obtained from the original specimen and from the 3D model are comparable, and that the margin of error is insignificant. To date, few studies have ever demonstrated whether the data obtained from 3D models replicate data taken from original specimens (Tocheri, 2009; Sholts *et al.*, 2010; Kuzminsky *et al*., 2012), or even whether currently available freeware generates reliable data with both methods (i.e. the original specimen and 3D model) and whether these two data sources are comparable (Muñioz-Muñioz *et al.*, 2016).

The aim of this study was thus to determine the degree of error between measurements of 3D models and original specimens using low-cost equipment in the case of small (50–57 mm length) hedgehog skulls from a zoological collection. We assessed the repeatability of both methods (direct measurement *vs* 3D images) by using a cheap scanner and a freeware program.

Material and methods

The material used in this study consisted of the skulls of 14 adult, subadult and juvenile male and female Algerian hedgehogs *Atelerix algirus* collected from different parts

Table 1. Specimens in the MCNB collection from which 3D models were taken.

Accession number	Sex	Age	Place and date of collection
MZB 2011-0806	Female	Juvenile	Lleida 8/I/2011
MZB 2011-0961	Female	juvenile	Catalonia < 2011
MZB 2010-1281-B	Female	subadult	Tàrrega 10/VIII/2010
MZB 82-0297	Female		El Pla de Santa Maria II/1923
MZB 95-0397	Female		Lleida < 1995
MZB 2003-1113	Male	juvenile	La Sentiu de Sió 27/V/2003
MZB 96-0458	Male	juvenile	Lleida 1/IV/1996
MZB 97-0227	Male	juvenile	Lleida 16/XI/1996
MZB 82-0294	Male		L'Hospitalet de Llobregat VIII/1918
MZB 82-0298	Male		El Pla de Santa Maria IX/1923
MZB 98-0262	Male		Almacelles 11/II/1998
MZB 99-1010	Male		Lleida <1999
MZB 2009-0037		adult	Lleida 10/I/2007
MZB 97-0228			Lleida 10/II/1997

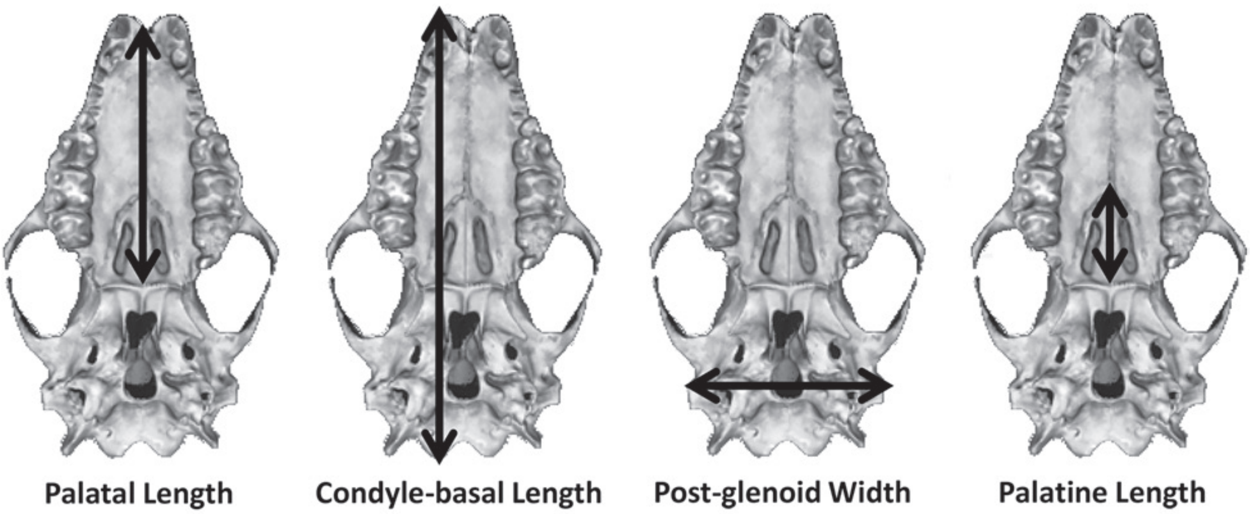

Fig. 1. Diagram of the measurements taken. LP: Palatal length; LPM: Median palatine length; LCB: Condyle-basal length; APG: Post-glenoid breadth.

of Catalonia in the period 1918–2011 (Table 1). These skulls are preserved in the osteological collection of Barcelona Natural History Museum (MCNB).

Atelerix algirus is a member of the Erinaceidae family whose craniometric measurements have been compared in articles and other published works (Gosàlbez, 1987; Frost *et al.,*1991; Corbet, 1988); both fossil and living species of this family possess distinguishable craniometric features that are used in taxonomic and zoogeographic studies (Butler, 1980; Frost *et al.,*1991; Krystufek, 2002; Ulutürk & Coskun, 2011).

Four craniometric measurements based on von den Driesch (1976) and Gosàlbez (1987) were taken, 1) Palatal length: distance from the anterior border of the palate (taken from between the animals' incisors) to the anterior wall of the transverse crest on the posterior border of the palate; 2) Condyle-basal length: distance between the anterior point of the premaxilla and the posterior border of the occipital condyles; 3) Postglenoid breadth: maximum width between the edges of the postglenoid process, 4) Median palatine length: maximum length of the suture between the two palates, from the anterior border to the anterior wall of the transverse crest on the posterior border of the palate (Fig. 1). All measurements are given in millimetres.

To obtain the 3D models of the skulls, we used a Next Engine Desktop 3D® scanner (NextEngine™, Malibu, CA, USA), along with the associated ScanStudio HD (NextEngine™, Malibu, CA, USA) software. We ran both the hardware and software on a non-expensive computer (AMD Phenom II X5 1050T® microprocessor with multi-core Thuban 45nm technology) (Advanced Micro Devices™, Sunnyvale, CA, EE.UU) with 8GB RAM memory DDR3 @669MHz and a NVIDIA GeForce 8400 GS 512MB® graphic card (Nvda Corporation™, Santa Clara, CA, USA).

The NextEngine scanner projects a series of laser beams onto the object to be modelled to generate a digital description of the surface of the scanned objects, which the associated software then interprets to build the 3D model. The laser beam moves over the object's surface and a sensor in the scanner calculates the position (distance) of the surface from the scanner and a three-dimensional system of coordinates (x, y, z) to draw a cloud of points. This cloud is an approximate representation of the scanned object, that is, the 3D model. It can be saved as a digital file and be used at a later date (Tocheri, 2009). To edit and improve the resulting model, the open-source code Meshlab® (ISTI – CNR, Pisa, Italy) was used. This program reconstructs the cloud of points saved in the file and enables them to be merged to create the final model.

The object to be modelled can be understood as a prism with sides, a base and a top. The protocol followed to obtain the 3D models from the object consisted of a number of different steps. First of all, the skulls were scanned using the NextEngine Desktop 3D scanner. All the 3D models were obtained using a minimum of five scans: two 360º scans from nine angles for the sides, followed by at least three scans for the base and three scans for the top, each scan consisting of three images captured from different angles. Average high-resolution model settings were chosen in ScanStudio™ (a density of 40.000 points per square inch). The scanning process generated partial models that were then aligned with ScanStudio using 3 – 9 hand-selected pinpoints. To select these points in the ScanStudio interface, we chose identical points on the screen in all the partial models, which gave a series of aligned range scans or a 'rough' version of the model, which we refer to as the 'pre-model'. This pre-model was saved in a Polygon File Format (ply) format and imported into the free source program Meshlab® to finish editing and obtain the final model. In Meshlab, we selected the option *Surface Reconstruction: Poisson*, an approximation technique. This method uses four variables: Octree Depth, Solver Divide, Samples per Node, and Surface Offsetting, which were awarded the values 14, 6, 1 and 1, respectively. These are the optimal values for the characteristics of the computer used. Although it could be argued that 14 as octree depth in Poisson-merging is too much for this kind of geometry, we decided to use this value given that the scanning method was conceived for the whole zoological collection of the Museum, which contains animals of a great variety in size (invertebrates and vertebrates). A value below 14 octree gave certain undesirable 'wide spots' in small or thin animal structures such as antennae, insect legs and small bones). However, our computer crashed when using an octree value over 14. Hence, an octree depth of 14 helps create a solid model without cavities that simplifies points and smoothes out textures.

Given their size and to ensure that they could be handled by computers, once fully edited by Meshlab, the 3D models were simplified using the tool *Quadratic Edge Collapse Decimation,* a standard with 300.000 faces that simplifies flat areas whilst maintaining the detail in curved areas. Given that the model could have a resolution as low as 300.000, we opted to use a low-resolution model as our computer was not very powerful. Thus, our procedure imitated a real situation of a scientific institution with limited economic resources.

Once the 3D models for each skull had been completed, the measurements of the chosen craniometric variables was conducted with Meshlab (option *Measuring Tool*) in two different ways: 1) measurement on screen with the whole skull visible at 100% zoom (hereafter, 'screen') and 2) measurement on screen using the zoom option (not quantifiable with Meshlab) to give the best possible visualization for measuring without losing perspective (hereafter, 'screen with zoom'). Skull measurements were taken from the original specimens using Mitutoyo® CD-15CPX digital callipers (hereafter, '*original*'), with a resolution of 0.01 mm and a tolerance of +/– 0.02 mm at an environmental temperature of 20° C.

Data processing and statistical analysis

For each skull, two measurements of each of the four variables were taken by a skilled and trained worker (SG) using each of the three methods with no specific sampling order. At least a whole day was allowed to elapse between the first and second series of measurements to avoid unwitting reference during the second series of measurements to the values obtained in the first series. These data were used to analyse the repeatability *within* each method (INTRAMETHOD). However, to compare the two methods, one of the measurements taken with each method was chosen at random and the repeatability *between* the results of the *original* method and those of the method that used the 3D models were analyzed ('*original' vs*. '*screen*' and '*original*' *vs*. '*screen-zoom*') (INTERMETHOD).

During the data-gathering, 14 skulls were scanned to obtain 14 3D models. Nevertheless, in some cases the skulls were found to be damaged and measurements could not be taken from the original models or from the 3D models. Thus, the number of samples varies in each sample from 11 to 13 (Table 2). The steps taken and the algorithms used during the scanning process were logged in a database in which the time taken to obtain each model was also recorded.

To calculate the repeatability, a one-way ANOVA was employed in which the individual samples were the factors and the measurements (obtained either with the INTRAMETHOD or the INTERMETHOD) were the factor levels. Using the variance components, an index of repeatability was calculated by means of the following formula:

$$Ri = \frac{S^2(effect)}{S^2(effect) + S^2(error)}$$

where S^2(effect) is the variance between groups (between individual hedgehogs) and S^2(error) is the variance within each group (between measurements taken for each hedgehog).

Table 2. Repeatability values of the different measurement methodologies employed to measure the craniometric features, and comparisons between the different methods. Repeatabilities (ri) are given as scores with a maximum of 1.

	Palatal length				Condylo-basal length				Postglenoid breadth				Median palatine length			
	Error df	F	ri	p	Error df	F	ri	p	Error df	F	ri	p	Error df	F	ri	p
Original	11	63.08	0.97	<0.001	11	3071.79	0.99	<0.001	11	511.90	0.99	<0.001	14	30.53	0.94	<0.001
Screen	11	46.59	0.96	<0.001	13	967.28	0.99	<0.01	12	531.28	0.99	<0.001	11	4.62	0.64	<0.001
Screen-zoom	11	29.18	0.93	<0.001	11	238.84	0.99	<0.001	12	167.66	0.99	<0.001	13	72.81	0.97	<0.001
Original vs. screen	11	26.30	0.93	<0.001	11	339.01	0.99	<0.001	11	53.91	0.96	<0.001	13	6.87	0.75	<0.001
Original vs. screen with zoom	11	25.81	0.98	<0.001	11	242.70	0.99	<0.001	11	57.94	0.97	<0.001	13	8.23	0.78	<0.001
Screen *vs.* screen-zoom	11	52	0.96	<0.001	11	593.61	0.99	<0.001	11	206.29	0.96	<0.001	13	16.96	0.89	<0.001

Results

Our results show that all the measuring methods used are inherently consistent (INTRAMETHOD) and gave repeatability values of over 90% (ri = 0.90) for all the measurements taken (Table 2). The only exception was the measurements carried out on 'screen' of the median palatine length, which had a repeatability of just 64%. Nevertheless, a review of the data revealed that in this case a single sample was responsible for 27% of the measured error and that without this particular measurement the repeatability value was similar to the remaining values (ri = 0.91; p < 0.001).

When we compared the three methods (INTERMETHOD), we found that the results were very comparable since they were highly repeatable for almost all the measurements (palatal length, condylo-basal length and postglenoid breadth). Nonetheless, in the case of the median palatine length the repeatabilities of the measurements taken directly from the skulls and those calculated on screen (both with and without zoom) are high but with a margin of error of 23 – 25% per measurement (Table 2). The repeatability between the measurements on screen (with and without zoom) also gave high repeatability values but without reaching the expected levels (ri < 90%) (Table 2). Given that in the on-screen methods without zoom an atypical result was detected, the repeatability calculations were repeated without the measurements from this particular skull; nevertheless, the repeatability values barely changed ('*original*' *vs*. 'screen': $F_{(12, 13)}$ = 7.31; ri = 0.76; p < 0.001; 'screen' *vs*. 'screen-zoom': $F_{(11, 12)}$ = 15.42; ri = 0.88; p < 0.001), which suggests that this individual skull measurement was not the cause of the loss of repeatability between the methods.

Discussion

In this study four craniometric measurements were taken from each *Atelerix algirus* skull using both the *original* specimen and 3D models to determine whether the results derived from the application of this latter method are comparable with those taken directly from the former. The results show that both methods are very consistent and that there is a very small margin of error. As well, in most cases the measurements taken were very (ri > 70%) or very highly (ri > 90%) repeatable between the two methods. Measurements taken from 3D models replicate with only a very small margin of error those taken from directly from specimens. Thus, our study demonstrates that measurements taken from 3D models of zoological specimens in the size range studied are as suitable for the scientific study of morphological variation as measurements taken from originals even when using low-cost equipment. Despite this, the repeatability values for the measurement of the median palatine length were markedly lower than for the rest of the variables. It is important to bear in mind that palate length may be a characteristic difference between the genera *Atelerix* and *Erinaceus* (Frost *et al.,* 1991; Gosàlbez, 1987; Corbet, 1988). According to our results, measurements carried out on 3D models that are delimited by the borders of the skull (palatal length, condylo-basal length and postglenoid breadth) are more reliable than those delimited by the sutures (median palatine length). We believe that this limitation is due either to a lack of contrast in the image of the model or a lack of definition in certain structures (sutures, small cavities). This contrast lessens the error in the measurements taken from the 3D models. It is worth adding that the NextEngine scanner incorporates a pre-treatment package for originals that can eliminate brightness; however, we did not use this package in our protocol and its use could improve the repeatability.

The sources of error in measurements are closely linked to the range of variability found in each biometric measurement, the equipment used, the ease with which measurements can be physically taken and defined, and the skill of the worker in taking biometric measurements (Lesser & Boag, 1987; Senar, 1999). Given the same observer error and equipment precision, biometric variables with a large amount of variance between individual samples within a population will lead to more measurement error. Likewise, more precise equipment will ensure less measurement error. Thus, if equipment is used that assures greater precision in the taking of measurements (for example, a ruler or callipers with markings of less than a millimetre), the measurement error will be less. 3D models allow measurements to be taken with a zoom that brings the measurement points much closer. Nevertheless, when the ri values for the *original* method are compared with the 3D models (both with and without zoom), the improvement offered by the zoom does not give any increase in repeatability (or reduce the measurement error) over 3% (Table 2).

The skill of the worker when taking measurements is another important factor to take into account when trying to reduce the error. Some biometric measurements are difficult to take and require a certain degree of skill and protocolization, and so a trial period is recommended. A possible solution for the taking of measurements such as the median palatine length or of those with repeatability values of less than 90% is to measure the variable in question from the same sample a number of times and then calculate the mean (Senar, 1999). If the variable to be measured is a suture, one possible way of improving the repeatability could be digital pre-treatment of models to, for example, reduce brightness or mark fissures more clearly and make several measurements of the variable and than calculate the mean.

In light of the obtained results, we believe that the 3D models generated using the NextEngine Desktop 3D scanner and the ScanStudio software, and edited with the Meshlab open-access freeware, are of sufficient quality to be used in biometric studies of small vertebrates. Other authors have already suggested that open-access software can give optimal results when applied to 3D models (Falkingham, 2012; Muñoz-Muñoz *et al.*, 2016) and, given the price of optical laser scanner systems, the methodology described here is a good way of reducing the cost of the material needed. It is obvious that another factor to take into account is the relationship between the time taken to generate the 3D models and the use to which they will be put (Tocheri, 2009). In this sense and concentrating only on their scientific use, Tocheri (2009) notes that 3D models are useful for obtaining measurements of surfaces and volumes, two measurements that are difficult to take from an *original* but which can be reliably acquired from 3D models. As Tocheri (2009) comments, if the aim is to generate lineal measurements it is important to analyse costs in terms of units of time. We believe that all possibilities of creating museum collections of 3D models should be explored. Such a scenario will be of great interest for scientific collections in museums since 3D models will facilitate the use of collections, make collections more visible and provide practical solutions for different museum sections. For example, the existence of 3D models of an important collection will mean that researchers will not have to travel so far and will thus be able to save both time and money (Kuzminsky *et al.,*2012).

Models obtained from low-cost optical scanners are not yet totally apt for studies whose aim is to accurately measure or visualize sutures, cavities and other small bone structures (Tocheri, 2009). The loss of detail is due to the algorithms used by the software and/or the characteristics of the hardware (both the scanner and the computer). Even so, in our experience we have found that sutures are correctly visible in the initial scanning models *before* alignment and the final fusion take place (SG, JA-G pers. obs.). It may thus be worthwhile to conserve these partial models – that is, the incomplete parts of the pre-model – in the virtual collection and to make them available to researchers. On the other hand, these models are somewhat unattractive for the general public and are not of any great use as pedagogical tools. Besides the comparability of 3D models with real variables (e.g. this study), these digital methods do have other limitations. In the case of our study, these limitations were due to (i) the hardware used (both the computer and the NextEngine scanner); (ii) the fact that the software used in the modelization process is not the most powerful on the market; and (iii) the skill of the operator. Sholts *et al.* (2010) conducted a study of the repeatability of 3D models generated by two different operators, each using a different methodology to measure five human skulls. These models were also obtained using the NextEngine Desktop 3D Scanner and ScanStudio, and good repeatability values were achieved. The repeatability of our results, as well as the comments and data generated by Tocheri (2009) and Sholts *et al.* (2010), give scientific validity to proposed creations of collections of 3D models of museum specimens. Hence, the resulting repeatability values indicate that the 3D models generated with the NextEngine scanner and edited with the open-access freeware Meshlab are comparable with original specimens, at least, that is, if the specimens measured are in a similar size range to that of *Atelerix algirus*.

Thus, we believe that museums should increase the range of their collections by offering 3D models of their original specimens for both scientific and educational purposes. First, however, a digital library must be designed with an associated database such as that proposed by Rowe *et al.* (2001) that can allow quick easy access, and which contains logged details of the digitalization methodologies for all parts of the process and their relationship to the original collection. A collection of 3D models of original specimens provides museums with virtual visibility and offers practical solutions for museum sections. Furthermore, these models are scientifically and pedagogically practical and thus can help museums fulfil their functions as social institutions.

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Appendix

Measurements obtained from original specimens, from 3D images and from 3D images with zoom. LCB = condylo-basal length; LP = palatal length; LPM = median palatine length; APG postglenoid breadth. Empty cells correspond to measurements that could not be taken due to damage to the original skull specimen. All measurements are in millimetres.

	skull	skull	screen	screen	zoom	zoom
Accession number	**LCB_1**	**LCB_2**	**LCB_3D_1**	**LCB_3D_2**	**LCB_zoom_1**	**LCB_zoom_2**
MZB 95-0397	56.57	56.60	56.48	56.50	56.36	56.37
MZB 82-0297	49.69	49.68	49.54	49.60	49.65	49.14
MZB 2011-0806	54.84	55.07	55.20	55.42	55.40	55.39
MZB 82-0294	50.41	50.41	50.38	50.25	50.06	50.24
MZB 82-0298	50.16	50.09	50.37	50.27	50.00	49.95

Appendix continued.

	skull	skull	screen	screen	zoom	zoom
Accession number	**LCB_1**	**LCB_2**	**LCB_3D_1**	**LCB_3D_2**	**LCB_zoom_1**	**LCB_zoom_2**
MZB 98-0262						
MZB 2010-1281-B	54.55	54.54	55.16	55.19	55.11	54.55
MZB 99-1010						
MZB 2009-0037	52.66	52.71	52.68	52.60	52.24	52.44
MZB 97-0228	55.96	55.96	56.24	55.91	55.72	56.22
MZB 2003-1113						
MZB 97-0227	53.99	53.98	54.15	54.06	53.61	53.81
MZB 2011-0961	53.84	53.83	53.88	53.85	53.52	53.86
MZB 96-0458	53.07	53.20	53.04	52.78	52.94	52.71
Accession number	**LP_1**	**LP_2**	**LP_3D_1**	**LP_3D_2**	**LP_zoom_1**	**LP_zoom_2**
MZB 95-0397	28.92	28.99	28.81	29.08	28.97	29.04
MZB 82-0297	25.73	25.57	25.13	25.86	25.88	25.72
MZB 2011-0806	27.94	28.18	27.98	28.32	28.59	28.14
MZB 82-0294	28.03	27.47	27.34	26.88	27.56	27.16
MZB 82-0298	26.81	26.86	26.54	26.89	26.68	26.60
MZB 98-0262						
MZB 2010-1281-B	28.85	28.88	28.95	28.96	29.07	28.80
MZB 99-1010						
MZB 2009-0037	27.48	27.63	27.44	27.60	27.77	27.49
MZB 97-0228	28.96	29.21	29.34	29.26	29.12	29.78
MZB 2003-1113						
MZB 97-0227	27.51	27.57	27.84	27.59	27.66	27.71
MZB 2011-0961	28.33	28.67	28.34	28.41	28.39	28.38
MZB 96-0458	28.27	28.63	28.35	28.19	28.65	27.77
Accession number	**LPM_1**	**LPM_2**	**LPM_3D_1**	**LPM_3D_2**	**LPM_zoom_1**	**LPM_zoom_2**
MZB 95-0397	11.98	11.83	12.39	11.87	12.03	11.78
MZB 82-0297	9.49	8.92	9.72	10.25	9.64	9.73
MZB 2011-0806	11.49	12.01	12.14	11.66	12.28	12.43
MZB 82-0294	10.72	10.82	11.69	12.17	12.02	11.73
MZB 82-0298	10.97	10.81	11.51	11.54	11.38	11.47
MZB 98-0262	10.50	10.17	10.56	10.33	10.76	10.66
MZB 2010-1281-B	10.97	10.97	12.69	10.31	10.34	10.29
MZB 99-1010	10.91	11.21	11.82	11.44	11.22	11.19
MZB 2009-0037	10.33	10.63	11.39	10.81	10.44	10.27
MZB 97-0228	12.34	12.46	12.69	12.81	12.51	12.90
MZB 2003-1113	11.11	11.14				
MZB 97-0227	10.24	10.02	10.6311	10.3977	10.7557	10.5783
MZB 2011-0961	10.14	10.28	10.1911	10.4463	10.4589	10.5643
MZB 96-0458	11.93	11.42	11.4493	11.5839	11.388	11.7633
Accession number	**APG_1**	**APG_2**	**APG_3D_1**	**APG_3D_2**	**APG_zoom_1**	**APG_zoom_2**
MZB 95-0397	26.27	26.46	26.07	26.03	25.89	25.90
MZB 82-0297	23.25	23.48	23.03	22.96	23.02	22.94
MZB 2011-0806	25.64	25.60	25.98	26.05	26.15	25.98
MZB 82-0294	24.35	24.41	24.13	23.85	23.85	23.87
MZB 82-0298						
MZB 98-0262	25.15	25.19	24.94	25.02	25.13	24.89
MZB 2010-1281-B			26.25	26.27	26.11	26.32
MZB 99-1010	25.91	25.86	25.74	25.63	25.72	25.87
MZB 2009-0037						
MZB 97-0228	27.40	27.38	27.21	27.16	27.17	27.22
MZB 2003-1113	27.60	27.63	27.71	27.56	27.77	27.59
MZB 97-0227	25.72	25.70	25.43	25.38	25.44	25.59
MZB 2011-0961	25.89	25.76	25.61	25.68	25.65	25.15
MZB 96-0458	25.44	25.53	25.89	25.84	25.73	25.83