AN INVESTIGATION TO EXAMINE THE MOST APPROPRIATE METHODOLOGY TO CAPTURE HISTORICAL AND MODERN PRESERVED ANATOMICAL SPECIMENS FOR USE IN THE DIGITAL AGE TO IMPROVE ACCESS - A PILOT STUDY

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Abstract

Anatomico-pathological specimens constitute a valuable component of many medical museums or institutional collections but can be limited in their impact on account of both physical and intellectual inaccessibility. Further concerns relate to conservation as anatomical specimens may be subject to tissue deterioration, constraints imposed by spatial or financial limitations of the host institution, or accident-based destruction. In awareness of these issues, a simple and easily implementable methodology to increase accessibility, impact and conservation of anatomical specimens is proposed which combines photogrammetry, object virtual reality (object VR), and interactive portable document format (PDF) with supplementary historical and anatomical commentary. The methodology was developed using wet, dry, and plastinated specimens from the historical and modern collections in the Museum of Anatomy at the University of Glasgow. It was found that photogrammetry yielded excellent results for plastinated specimens and showed potential for dry specimens, while object VR produced excellent photorealistic virtual specimens for all materials visualised. Use of PDF as output format was found to allow for the addition of textual, visual, and interactive content, and as such supplemented the virtual specimen with multidisciplinary information adaptable to the needs of various audiences. The results of this small-scale pilot study indicate the beneficial nature of combining these established techniques into a methodology for the digitisation and utilisation of historical anatomical collections in particular, but also collections of material culture more broadly.

Keywords: visualisation, virtual museums, anatomical specimens, medical museums, object virtual reality, 3D PDF, photogrammetry.

1   RESEARCH AIMS

The main aim of this research was to increase the accessibility, and thereby the impact and educational value, of historical anatomical collections and medical museums to a diverse range of audiences. By drawing on the approaches of a variety of fields including but not limited to medical history, modern anatomy, heritage visualisation, and scientific publishing, it was attempted to show that it is possible to create a simple methodology which can be implemented even with limited access to software or expertise. It was endeavoured to create a methodology which could be used to create interactive digital versions of specimens with associated interdisciplinary educational output a) quickly and b) in a format which could be made available on the internet or in internal databases or virtual learning environments without requiring further expensive software, and thereby to increase the impact of these specimens in terms of education, research and public engagement, as well as contribute to the preservation of anatomical specimens by application of digital methods.

2   INTRODUCTION

Medical museums in general and anatomical specimens in particular constitute important and valuable resources for the material culture of medical history, as well as for understanding anatomical education past, and conducting anatomical education present. Anatomical specimens are of particular value on account of the frequently unique nature of preserved pathologies and atypical morphologies [1, 2]. However, anatomical specimens face challenges as they may be subject to deterioration and require periodic remounting or restoration of the preservation fluid [3], are susceptible to damage on account of their often fragile nature [4], and have been affected by changes in the medical curriculum which have altered the nature and extend of anatomy education in general [5, 6, 7] and reduced the

space and funding available to maintain and utilise anatomical collections in particular [8, 9]. Furthermore, anatomical specimens pose, perhaps more so than other museum objects, a problem of accessibility. Here the two main concerns are physical constraints of accessibility due to the architecture of the museum arrangement or a lack of display space for parts of the collection [10], and issues of intellectual accessibility on account of a lack of contextualising information suitable for non-specialist audiences. Given the importance of accessibility for the modern museum and educational material in general in order to render collections inclusive [11, 12], this was a particular concern of this research project.

Recently, digital technology has been widely used to increase the inclusiveness and impact of collections through the creation and dissemination of virtual objects. Visualisation methods have created new ways of engaging with museum and archival collections, and virtual museums and interactive exhibitions utilising digitised objects have been used with excellent results in heritage management, particularly concerning large and less accessible collections or more fragile objects [13, 14, 15]. While laser-scanning has been applied with excellent results to paleontological, zooarchaeological, and occasionally dry medical specimens [16-20], the promising results of photogrammetry, which unlike laser scanning does not require specialist equipment, in a variety of heritage contexts [21, 22, 23], prompted the investigation of this technique for anatomical specimens, although potential limitations with regards to reflection and refraction issues in glass-encased wet specimens were anticipated [24, 25]. Another visualisation technique which has found application with anatomical specimens [1, 26-28] is object virtual reality (object VR), sometimes called Quicktime Virtual Reality (QTVR). On account of these promising results, as well as the relatively simple methodology, and the fact that reflection or refraction effects have no impact on the outcome, this technique was likewise selected for the present project. Finally, in order to present and make available digitised specimens, the possibility to include 3D or general interactive content in portable document format (PDF) files which has been explored in both science publishing and heritage visualisation [21, 29-32] was chosen as the most suitable format on account of its free availability as well as its option to include 3D and other interactive content in addition to textual information.

While visualisation techniques have been occasionally applied to anatomical specimens, often by medical schools who have rediscovered the value of the anatomical museum [1, 4, 33-35], there remains much potential for expansion. In this paper, the combination and adaptation of established visualisation methodologies to accommodate the specific context and challenges of anatomical collections is proposed in order to increase the accessibility and ultimately the impact of historical anatomico-pathological specimens. This methodology was developed using wet, dry, and plastinated specimens from the historical and modern anatomical collections in the Museum of Anatomy at the University of Glasgow [10]. The museum includes specimens of human and comparative anatomy and pathology collected by William Hunter (1718-1783) and John Cleland (1835-1925), as well as a modern teaching collection. Specimens are preserved as wet preparations in either alcohol or oil of turpentine, or dry, either as bone specimens or as dried and varnished organs. The modern collection also includes resin casts and plastinated specimens. As such, the University of Glasgow holds diverse medical collections which lent themselves to digitisation as part of the present research project.

3   MATERIALS AND METHODS

3.1   Specimen Selection

In order to devise a methodology based on the principles discussed above, seven specimens of good conservation (displaying cardiac and renal anatomy) were selected from all three local collections. Specimens were comparative and human anatomical specimens, both typical and atypical or pathological, and included dry, wet, and plastinated specimens (Table 1). As such, the different materials allowed for a study of the benefits and limitations of different techniques for different objects.

Table 1. Specimens selected for digitisation.

Specimen catalogue no.	Description	Type
Cleland C.5	Heart of a harbour seal	Dry specimen
Cleland C.9	Heart with patent foramen ovale	Wet specimen
Cleland C.18	Heart with opening in interventricular septum	Wet specimen
Cleland G.27	Right Kidney with six separate renal arteries	Wet specimen
Hunterian 10.19	Heart at ca. age twelve	Wet specimen
Modern Renal Specimen	Kidneys with sections of abdominal aorta and inferior vena cava	Wet specimen
Prosection 06-07/22	Heart in mediastinum	Plastinated specimen

3.2 Digitisation and Presentation Methods

Photographs of the specimens were taken with a Canon EOS 600D digital camera with a 50 mm lens, using the semi-automatic 'Panorama' and 'No Flash' settings on account of their good balance between photographic quality and ease of acquisition. Image output was in the Canon-specific raw image format (.CR2), converted to Tagged Image File Format (.tiff) in order to avoid quality loss through compression at this stage. Objects were photographed in the Laboratory of Human Anatomy at the University of Glasgow using ambient light, and no specialised lighting equipment was used. Images for photogrammetry were taken both free-hand and using a generic tripod, selected or excluded based on subjective visual criteria and manual exclusion, and processed for photogrammetry in Agisoft PhotoScan Standard Edition (Version 1.0.2 build 1984; Agisoft LLC St. Petersburg, Russia), which yielded virtual objects in the U3D format. Images for object VR were obtained using a generic tripod and a simple turntable. The specimen was placed in the centre of the turntable and images were taken at 10° intervals, yielding 36 images per specimen. Post-processing of object VR images for background removal and improvement of light and contrast quality was achieved via Adobe Photoshop CS6 (Version 13.0.1; San Jose, CA, USA), which was also used to create labelled photographs for the output file. Virtual reality (VR) movies in flash format were created in Garden Gnome Software Object 2VR Object Movie Creator (Version 3.0 Revision 4.8.3; Vienna, Austria). Supplementary information was created in a word processor and exported as PDF, and interactive content embedded or created in Adobe Pro XI (San Jose, CA, USA).

3.2.1 Photogrammetry

On account of anticipated problems with glass-encased specimens, photogrammetry efforts were restricted to the prosection, the dry specimen, and two of the wet specimens. The images were processed in Agisoft Photoscan, which is user-friendly software that aligns the imported images, generates point clouds and subsequently a mesh from this data, and finally adds a texture based on the photographic information. The software was selected, as a license was already available to the research group. Parameters were generally kept at default settings with the exception of Dense Point Cloud Quality which was set to 'high', and some cases in which camera alignment could not be obtained without modifying the camera alignment parameters between low and high. The point cloud bounding box was manually reshaped to fit the object size and prevent excessive computing of unrelated points, and any superfluous points of the cloud or mesh were likewise manually removed. Any holes in the resulting mesh, as applicable to the dry and the plastinated specimen, were closed via the software-inbuilt 'close hole' functionality. The textured complete mesh was exported as universal 3D format (U3D) for embedding into PDF.

3.2.2 Object Virtual Reality

Post-processed image series were imported into Object 2VR, where a virtual object that could be rotated in both directions around a central axis, as well as investigated through zoom functionalities, was created. This software was selected from the available commercial options as suitably cost-efficient and user friendly. As no camera rig (which is required for a full 3D object [27]) was available,

an axial model was considered sufficient for the present aims. The object was supplemented with an interface modified from a default model provided by the software, which included controls for rotation and zoom, and allowed for the addition of information such as specimen description or material from the collection catalogue [3]. For one of the specimens, the 'hotspot editor' function was explored which allowed to label individual anatomical structures, and to display their names when the mouse cursor was placed over one of the eight structure thus labelled. The final model was exported as a Flash file (.swf) which could be embedded in PDF as well as opened in a standalone player.

3.2.3   Output Formats and Supplementary Information

The object VR as a Flash file and, in case of the prosection, the photogrammetric result exported as U3D, were embedded into a PDF file in Adobe Pro XI. The PDF's content included photographs of the specimen, a quotation from the historic catalogue (if applicable), the object VR model, labelled photographs drawing attention to specific anatomical structures, and a menu linking to the following sections of the document which included a description of the historical collection, and a discussion of the relevant anatomy both in modern and historical terms. The final section included a brief and simple quiz involving questions and answers on relevant anatomy; answers could be made visible or invisible by clicking simple buttons. The overall layout was chosen to resemble a website (including links and 'back' - buttons redirecting to the menu page) to allow for an easy and familiar type of navigation.

4   RESULTS AND DISCUSSION

4.1   Photogrammetry

Excellent results were obtained for the plastinated specimen. The surface texture was of a high quality, resulting in an accurate virtual model (Fig. 1). Minor flaws included a 'hole' where a section was not easily photographed, and which was consequently closed via the software-inbuilt modelling functionality. Export into Meshlab (version 1.3.3, open source, University of Pisa, Italy) or other graphic design software was considered for both hole modification and polygon count reduction, but not deemed necessary on account of the insignificant importance of this part of the model and the importance of high quality over low polygon count. In terms of the image acquisition method, results from free-hand and stationary cameras were comparable, although problems were encountered with camera alignment and thus model acquisition if the object was kept stationary. While these could in some cases be resolved by manipulation of camera alignment parameters, and while stationary image capture allows for the same methodology to be used for both photogrammetry and object VR, using free-hand photography for photogrammetry is perhaps advisable as in some cases the camera alignment problems could only be resolved by taking a new set of photographs.
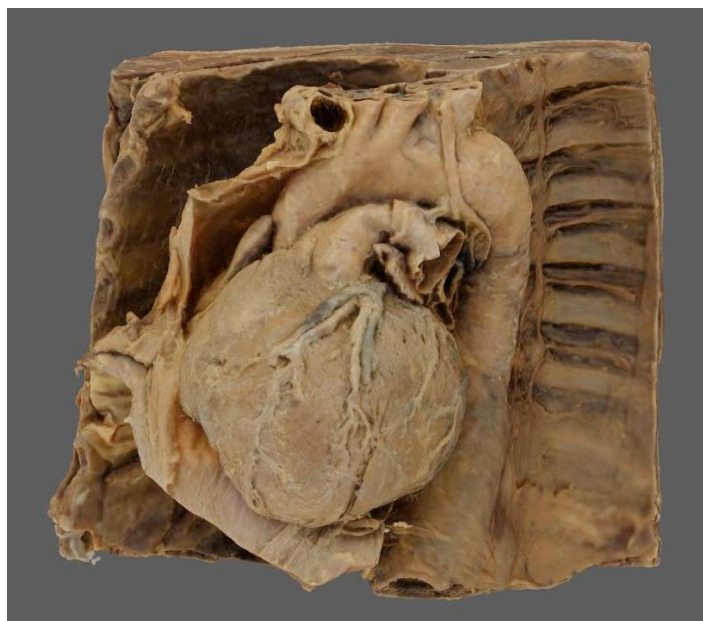

Figure 1: Digital model of plastinated prosection, obtained via photogrammetry.

Similarly good results were obtained for dry specimen, although problems were caused by the glass jar which prevented visualisation of the bottom of the specimen (Fig. 2). For aesthetic reasons, it was decided to recreate the glass bottom rather than keep the specimen with a hole; as such, the same 'hole closing' functionality as above was applied, with similar future potential for utilising more accurate modelling software. Further limitations included the labels on the glass, which were interpreted by the software as part of the specimen and thus resulted in an inaccurate virtual model; similarly, distinction of closely adjacent structures, such as the branches of the aortic arch, was not ideal and white cloudy artefacts remained in between the structures. Nevertheless, the texture and quality were excellent, and no particular problems were encountered on account of light reflection through the glass. As such, this method would lend itself to other dry specimens, such as varnished organs or resin casts which are frequently mounted rather than resting on a base, and to bone specimens, which could be suspended to allow for capture from all angles. This would prevent problems such as the failed attempt to acquire usable photographs from underneath the specimen, although this problem might similarly be addressed with a more elaborate camera set-up and a glass table, as successfully done in the context of photogrammetrical gait measurement [36].

Figure 2: Dry specimen visualised by photogrammetry, showing parts of container and label interpreted by software as part of specimen.

As anticipated, wet specimen capture was found to be problematic on account of reflection and refraction. The resulting models were often distorted or incomplete because of the effects of preservation fluid and the inability to obtain adequate photographs of the top and bottom of the specimen (Fig. 3). As such, this approach was abandoned, but it was concluded that these issues might be resolved with a more elaborate photographic set-up and processing software which compensated for distortion. Continuous research in fields such as underwater or two-medium photogrammetry [37, 38] may provide insights into addressing these issues, and as such the possibility of eventually using photogrammetry for wet anatomical specimens is still under consideration.

Figure 3: Wet specimen visualised by photogrammetry, displaying artefacts
from preservation fluid and problems caused by glass reflection.

4.2   Object Virtual Reality

Object VR results for all material types were of excellent quality, highlighting the particular usefulness of this method for anatomical specimens (Fig. 4). Interactive virtual objects were obtained for all specimens, and there were no limitations as a result of glass containers or preservation fluid. Once the methodology had been established and the best camera settings and post-processing criteria determined, models could be created reasonably quickly, with image acquisition and object VR times of under half an hour per specimen; the most time-consuming aspects were the image post-processing in Photoshop CS6 and, if applied, the hotspot labelling, bringing the time per specimen to between four and eight hours, although this time is likely to decrease with expertise and optimisation. The addition of hotspot labels, while time-consuming, was considered to be an approach which increases understanding of the anatomical structures of the specimens in a way which was more interactive and conductive to spatial learning than more traditional labelled photographs of front- and side- or back- views (which were nevertheless also provided with the output PDF file to provide complementary educational approaches). The results could be viewed either in a standalone Flash viewer, opened in a web browser, or (as intended) as part of a PDF; for the latter two options, an up-to-date Flash plugin is required which is available for free download [39].

Figure 4: Front view of wet specimen object VR, including interface controls at the bottom.

4.3 Portable Document Format Files and Additional Content

The resulting U3D and Flash files could be embedded into a PDF file using Adobe Pro XI without any issues. The software is easy to use without previous experience and thus allows for reasonably quick and straightforward assembly of the multidisciplinary output files once the relevant content has been created. It furthermore allows for the use of links and creation of buttons which make navigation easier and more accessible on account of their resemblance to websites which the user may already be familiar with, and additionally permits the creation of simple quiz facilities (Fig. 5). As PDF furthermore includes a screen reader functionality, allows for the inclusion of audio content, and provides options to increase font size, this may indicate the suitability of this output format for increased inclusiveness in the context of disability as well as complementary learning styles. Similarly to Flash, Adobe Reader finds frequent use already, but if it is not available on a computer it can be downloaded for free from the producer's website [40]. As such it allows for the presentation of the interactive content without need for specialist software.

Figure 5: Screenshot of typical PDF layout including labelled photographs, catalogue text, interactive object VR specimen, and navigation menu.

A limitation to be addressed is that while non-proprietary PDF viewers are available, the interactive content only works with the Adobe PDF viewer and Flash plugin, which may cause problems with machines operating on Linux, or on mobile devices. It is possible to create interactive PDF files in and for open source software, and this issue as well as potential solutions have been addressed in the literature [21, 30, 31]. However, these approaches require substantially more coding and computer expertise than the utilisation of proprietary software, and as such it was decided to accept the cost and limitations in order to maintain comparative simplicity and potential for realistic implementation.

5 CONCLUSION

This paper has attempted to show the vast potential inherent in applying photogrammetry and object VR to anatomical collections and combining these methodological approaches with the format of interactive and 3D PDF. As emerged, object VR was the preferable method for wet specimens, but photogrammetry is a possible methodology for dry and plastinated specimens. Using these methods can improve the accessibility and educational value of historical and modern anatomical specimens, particularly if they are presented in form of an interactive PDF with supplementary multidisciplinary information. The proposed methodology furthermore holds value from an archiving and conservation perspective as specimens can be preserved virtually as well as physically through creating and archiving their digital version, a general benefit of digital visualisation [15, 19]. The methodology has particular merit as it does not require extensive specialist expertise, software, or equipment, and can thus be realistically implemented in collections with time and budget constraints.

On account of the preliminary nature of this research, there is ample scope for further research, particularly regarding the improvement of the visualisation quality, the expansion potential for both supplementary content and range of digitised specimens, and in the context of quantification. Thus, complete 3D object VR specimens may be obtained via a camera rig, and the compensation for optical effects on wet specimens is envisioned, as is the extension of visualisation scope through planned digitisation of larger numbers of the specimens at Glasgow. The modification of additional information to cater more specifically to the learning and access needs of different audiences is another key concern. Finally, a future aim is the quantification of the conducted research via questionnaires and feedback obtained from groups encountering the specimens in different educational contexts.

The presented methodology holds much potential for enhancing the impact of anatomical collections with regards to education, accessibility, conservation, and public engagement. While the individual components used are not new, it is argued that the combination of photogrammetry, object VR, and interactive PDF results in a methodology of profound use for medico-anatomical museums in particular, but also for heritage collections more broadly. It is hoped that application of this methodology will increase awareness of the value and potential inherent in multidisciplinary approaches to historical anatomical collections, as well as the collections themselves.

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