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Exploring public perceptions of creating and using 3D printed human remains☆

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ABSTRACT

3D printed human remains offer an alternative presentation format to traditional photographs, that could be more effective and less emotive. However, the perception of the public regarding key questions, such as the use, ownership, and disposal of 3D printed remains in courts of law has not yet been established.

This study explored whether the creation of 3D printed human remains could be considered as an ethical practice by members of the public. A survey comprised of 36 questions was designed to gather responses from members of the public (n = 400) about their attitudes to the creation and use of 3D printed human remains. A majority of respondents believed it was ethical to use 3D prints in courtroom demonstrations (more than 90%) and that this may help jurors to better understand expert testimony over photographs. Respondents also indicated that the context of the case and whether consent had been received from next of kin were important considerations.

The results of this study indicate that there is a recognition that there is a direct connection between 3D printed remains and the individual from whom a print derives, and that there is a clear public interest in ensuring that prints are used ethically and responsibly. Yet there are currently no guidelines for what constitutes best ethical practice for the creation and utilisation of 3D prints. As we look forward, there is a need to identify how best to treat 3D printed remains with dignity and respect in casework in a manner that is also contextually appropriate.

1. Introduction

The use of 3D printed human remains has gained increased recognition in medico-legal applications. The ethical considerations concerning the incorporation of 3D forensic science (3DFS) [1] into practice has been recognised as an important area for future research [2–4]. The use of 3D printed human remains is a potentially challenging area from an ethics point of view because it sits at a complex intersection between forensic science, anthropology, medicine, law, engineering, computer modelling, osteoarchaeology, and philosophy. The utility of 3D printed human remains has been explored in forensic medicine [5], forensic imaging [6], forensic odontology [7], and bioarchaeology [8]. There is evidence of their use in forensic practice in the UK [9,10], with 3D printed remains being shown to have the potential for multiple applications, such as establishing physical fit [9,11], the visualisation of trauma [12,13], and for courtroom use and improving juror comprehension [14–16].

As such, it is clear that 3D printing is increasingly being used in medico-legal practice with the advancement of 3D printing technologies and capabilities. It is, therefore, important to consider how to create and use 3D printed human remains in an appropriate way that ensures the dignity of individuals. The use of 3D prints in crime reconstruction activities raises many important questions such as, who owns the prints, should the next of kin provide consent, and how should such prints be preserved or disposed of once they have been utilised in court. As such, the public perception of the presentation of human remains in courts of law (along with broader issues such as the use of 3D printed materials) is an important consideration that needs to be incorporated into

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developing commonly agreed best practice guidelines.

To date, such issues have not been addressed in the published literature. Gauging public opinion regarding the application of 3D printed human remains in crime reconstruction scenarios creates opportunities to ensure a broad range of viewpoints can inform best practice, particularly given the potentially emotive value of human remains and the link between the print and the deceased.

1.1. Public perception of the display of human remains

Public support for the display of human remains in museum settings has been identified [17], as well as for use in research [18]. However, there are differing opinions when it comes to the display of remains of a sensitive nature, such as infant remains [18,19]. In a recent study, Alves-Cardoso and Campanacho [20] explored the feelings of the public from a sample population with a majority (95%) of Portuguese participants (n = 312) about the creation, access, and dissemination of 3D human remains from a cultural heritage perspective. 43% of respondents agreed that 3D digital replicas should be considered with the same ethical considerations as real human remains regarding their display online, whereas, 42% disagreed. Hirst et al. [18], in their survey of international participants (n = 55) noted that, 26% felt that 3D printed or digitised human remains should be treated the same or similarly to real human remains, while 55% considered 3D printed or digitised human remains to have less ethical requirements than real remains, and 22% thought 3D reproductions had no ethical requirements [18]. Alves-Cardoso and Campanacho [20] also reported that a high proportion (87%) of respondents would be OK to have their own or their family members skeleton displayed, although the context of display was not made explicit. As such, there appear to be conflicting views about whether digitised remains have the same ethical considerations as real remains, and it is not known what factors are influencing this decision making.

Human remains and their analysis are popular topics in the media for their ability to capture and garner the attention of the public [21], however their use in public displays (museums, exhibitions, media etc.) should be carefully considered. A survey by English Heritage [17] investigated public views on the display of human remains in museums (n = 864 adults in England), the majority of respondents (91%) agreed that human remains should be allowed on display in museums, and 84% of respondents felt that the display of human remains in museums did not show a lack of respect for the deceased. While 48% felt that how old the bones were was a limiting factor that should be considered [17], the findings indicated that there was broadly strong support from the public for the display of archaeological human remains in museums.

In contrast, the display of medical specimens and the remains of babies are areas that can cause greater concern [19,22]. The study by Hirst et al. [18], considered the relationship between 3D prints of human remains and real human remains and surveyed the opinions of museum visitors. The majority (94%) of the participants (n = 56) were positive about the use of human remains in research with less support for their use in museum displays (65% positive) [18]. Moreover, 94% of the respondents were happy for their remains to be printed after their death and for use in teaching or research, but respondents responded negatively towards those prints being taken home for unsupervised study by students [18]. It is apparent that concerns can vary depending on the type of remains being displayed, their context and their application; each scenario for the use or display of remains warrants individual consideration. The BABAO Code of Ethics also suggests that the views of genealogical descendants and affiliated cultural communicates should be considered when publishing images of human remains [23].

1.2. Public perception of photographs of human remains

Physical human remains are not always the subject of an exhibit; traditionally photographs have been used and more recently 3D reproductions have been introduced [24]. The power of distressing photographs has been explored previously, with, for example, a series of photographs titled 'Death and Disaster' in the 1960s that attempted to challenge perceptions of the display of human remains [19]. The series was comprised of press photographs from car crashes and accidents, including deceased bodies and aimed to confront the fascination with violence and death held by the general public [19]. Furthermore, disturbing photographic exhibits in a courtroom can be difficult for members of the courtroom to view [24]. The display of photographs offers transparency and an ability to generate an emotive and intimate effect on people; something that is imperative to consider when debating the ethics of displaying photographs of the deceased [19].

In an exploration of the ethical considerations of the display and analysis of mummified remains of children at a historical site in Italy, Squires and Piombino-Mascali [22] asserted that photography by the public should not be allowed, and that taking photos of the remains is disrespectful. However, an image showing the remains of the children is included in the article revealing the importance of context and accessibility. The use of images of this nature for educational purposes is another context that should be considered when making decisions about what to display and where. For example, The British Museum has images of a *"Mummy of a very young child"* freely available online [25].

Wider concerns regarding photographs of human remains, include the taking of 'selfies' with bones in museum or academic teaching settings [26] and the subsequent sharing of these photographs on social media platforms [27]. The sensitivity of taking photographs of human remains often varies with the context, for example, photographs can often be prohibited from being taken, such as in The Hunterian Anatomy Museum, Glasgow and in the Body Worlds exhibition in the UK, although this same exhibition in Amsterdam did not have this restriction [27]. Anthropologists and archaeologists must endeavour to be mindful of the purpose of their actions and of their actions themselves, whilst also respecting the power that photographs have to unsettle people or cause distress [19,22]. Moreover, this warning may also be applied to the production and exhibition of 3D remains and echoes the recommendations in the BABAO imaging guidelines [28]. Interestingly a survey of Australian anatomy students (n = 483), found that respondents had a greater preference for donating their own medical images (81%) in comparison to donating their own bodies (43%). This is a valuable insight that indicates that 3D images, and potentially 3D prints derived from those data can provide an alternative means of contributing data for research that reduces barriers in certain contexts [29].

Given the ease of sharing photographs in the modern world and especially on social media, Errickson and Thompson [27] set out the importance of considering context, intent and possible gains. For example, factors such as where did the remains come from (context), what is the intent in sharing these images (non-maleficence), and what is hoped to be gained from sharing the images (beneficence) can be contrasted and balanced to determine the ethical inferences alongside the factors of permission, respect, justification, education, and awareness [27]. Consideration of these principles assist with the consideration of displaying photographs of human remains, may offer valuable insights for the creation and utilisation of 3D prints of human remains in crime reconstruction practice going forward.

Protecting the dignity and respect of the deceased and/or their family is the fundamental principle guiding ethical work with human remains, whether modern, archaeological, real or digitised [30–32]. Passalacqua et al. [33] even go so far as saying that publication titles should show respect for the deceased and their families. Such high standards towards ethical guidance in forensic anthropology are somewhat contrasting to the lack of guidance of how to act ethically with regards to digital and printed human remains [34]. This needs to be addressed urgently given the increasing use of digital remains, the availability of downloadable models online, and the increasing affordability of 3D printers [35].

1.3. Acting ethically in 3D forensic science

While current guidance addressing the use of human remains in their broadest sense may recommend principles to follow, such as acting ethically, responsibly, respectfully and justifiably [28,36], there is very little published guidance that sets out what this might look like in practice, how ethical practice can be assessed and whether public opinion reflects the underlying principles of ethical best practice.

This paper presents the findings from a study that was designed to understand the public perception of 3D printed human remains and establish how public perception intersects with the ethical considerations of creating and using such 3D prints. The principles of anonymity, autonomy, beneficence, consent, context, justice, non-maleficence, proportionality, and transparency are all relevant factors that may influence the public perception of the use of 3D printed remains in courts of law, Insights from this study can be used to inform the articulation of an ethical framework to guide and enhance the transparency of the creation and application of 3D imaging and printing in forensic science.

2. Materials and methods

2.1. Study design: preliminary survey

A preliminary survey was carried out at the Being Human Festival, Liverpool, UK, which was designed to gain initial insights into the public view of the use of 3D printed bones in courtrooms. Participants were asked to view and handle six clavicle and six metatarsal prints and then complete a short survey to see how they felt about printed bones. The survey was presented digitally using a computer tablet and hosted by an online survey platform where participants were asked three short questions:

1. Would a 3D printed model help you to better understand forensic evidence than a photograph?
2. Would you mind a model of your skull being exhibited?
3. Which model(s) looks most realistic?

2.2. Study design: full survey

A full survey was then designed to explore the public perception of ethical considerations concerning the creation and use of 3D printing bones in forensic contexts. The survey was delivered in a digital format using the same online survey platform as the preliminary survey. A small number of participants were asked to complete the full survey to test that the link was active, and that the navigation of the survey was suitable. No issues or technical difficulties were raised, and no alterations were made. The survey link was disseminated through social media platforms, email lists, newsletters, and conferences from September 2018 until July 2020.

Introductory text specified that the survey questions considered the use of 3D printed human remains in forensic investigations, providing the context that non-invasive imaging could be used to create the prints, and that the remains were from individuals who had died recently in forensic cases (not archaeological).

2.2.1. Question design

The initial survey questions asked, 'Do you think it is ethical to create 3D printed representations of human remains?' Subsequent questions were designed to address one of five themes that had been identified from the published literature: application, consent, treatment, distribution, court room decision making. There was one additional 'concerns' category for free text responses. Each of these are categories and its source are detailed in Table 1.

2.2.2. Participants

The survey ran for almost two years to ensure as many participants could complete it as possible. Participants did not need to have a particular background or prior knowledge of 3D printing or human remains, as the aim of the survey was to gather opinion from the public, rather than from experts in this field. Convenience and snowball sampling approaches were taken by distributing the survey through social media. It is acknowledged that because established networks were used to distribute the survey it was more likely to be advertised to people working in forensic science or osteoarchaeology backgrounds.

2.2.3. Data analysis

Data were exported before being processed and analysed in Excel. The open text nationality and religion demographic data were cleaned for consistency, for example, fields recording British, England or UK

Table 1
Categories and origins of the full ethics survey questions (questions 18–36), following from questions 1–17, the introductory questions related to consent and demographic information.

Question category	Origin of category	Questions
Application	The intended use of the 3D printed remains was indicated to be an important decision-making factor to survey respondents by Hirst et al. [18]. For example, if the prints were being used for a good cause, for use in court or for a diagnosis, then this might influence the opinion of a participant. Exploration of using 3D printing when avoiding invasive autopsies was also included, given that some individuals and cultures can be against invasive post-mortem examinations [37].	Questions 18–22 requested responses addressing the application of prints in different contexts such as courtrooms, museums, and for decorative uses.
Consent	Consent was a common theme suggested by Jones[38], and later discussed in[39] when considering prints from living subjects or from donated cadavers.	Questions 23 and 24 requested responses addressing obtaining consent prior to producing a 3D print.
Treatment	Treatment of the printed remains (e.g., in handling and disposal) was another category included in order to determine whether prints are to be treated as human remains, i.e. whether the prints are meaningfully linked to the deceased, as discussed by Smith and Hirst [34].	Question 25–27 requested responses addressing the treatment of printed remains.
Distribution	Distribution was included to explore the ownership of the printed remains, as discussed by Hirst et al.[40] regarding digital 3D data.	Questions 28–32 requested responses addressing the ethicality of different distribution scenarios, such as sharing prints online, or for use in research or teaching.
Courtroom decision-making	Courtroom decision-making explored the use of a 3D printed bone in a courtroom as a visual aid, as advocated by Blau et al.[15] and later by Errickson et al.[16].	Questions 33–35 requested responses addressing prints as visual courtroom aids.
Concerns	This additional category afforded an open-ended question to gather further opinion from participants and identify any other concerns that might be not covered in the survey questions.	Question 36 formed an open text box for individualised responses.

were logged as 'UK'; and variations of Church of England, Christian C of E, or CofE were logged as 'Christianity (Church of England)'. In cases where two religions or nationalities were received, these were recorded as 'dual'.

The open text responses for question 36 (any other concerns or comments) were coded using descriptive and simultaneous coding by one researcher [41]. A descriptive code was given for each topic discussed; one comment could have several descriptive codes simultaneously assigned (simultaneous coding). The identified codes were then categorised into overarching themes through an iterative comparison [41] performed by re-coding the descriptive codes so that they were consistent between comments and categorising the codes until they fitted into a select number of overarching themes. The codes and categories used were identified after reading all of the responses.

3. Results and analysis

3.1. Preliminary survey

The findings from the preliminary survey (Table 2) indicated that the participants (n = 45) were broadly positive about the use of 3D models and prints. 80% of respondents agreed that a 3D printed model would help them to understand forensic evidence better than a photograph, and 73% of respondents would not mind a model of their skull being exhibited. Question three asked which of the 3D prints looked the 'most realistic', here there was a distinct preference for the SLS print (73%).

The findings from the preliminary survey informed the design of the final survey, which was then be designed to explore these topics further by asking more detailed questions regarding the creation and use of 3D prints.

3.2. Full survey

A total of 443 respondents engaged with the full survey between 2018 and 2020, after providing their consent (questions 1–11). There was a 93% completion rate, with the typical time spent being approximately eight minutes. 400 respondents completed the full survey.

3.2.1. Respondent demography

Demographic questions addressing age (Q12) and gender (Q13) indicated that 81% of respondents were between 21 and 49 years old, and 60% indicated female (Table 3). Question 14 revealed that 45% of respondents recorded their nationality as being from the UK, and 19% from the USA (Fig. 1).

Question 15 concerning religion revealed 27 different groups following data cleaning. The religions with a count of less than 5 were combined into 'other'. The majority of respondents (50%) recorded their religious identity as 'none', 18% identified with the denomination of Christianity, and 12% with Atheism (Table 3).

Answers to Question 16 revealed that the majority of respondents (90%) were educated to the level of a higher education degree (Table 3). Question 17 indicated that high proportions of respondents (>50%) had worked with human remains/deceased people, non-human remains, and/or in research (Table 3).

3.2.2. Survey question results

Questions 1–36 asked respondents to offer their opinions about 3D printed bones in different formats or scenarios. Question 18 revealed that a majority of respondents (90%) felt it was ethical to create 3D

Table 2
Responses to preliminary survey questions 1–3 (n = 45).

Survey question	Answer Choices	Percentage
Q1. Would a 3D printed model help you to better understand forensic evidence than a photograph?	Yes	80%
	No	2%
	Not sure	18%
	Total	*100%*
Q2. Would you mind a model of your skull being exhibited?	Yes	11%
	No	73%
	Not sure	16%
	Total	*100%*
Q3. Which model(s) looks most realistic? *Multiple answers accepted, thus 51 answers received	1 (Ultimaker 2; FDM)	16%
	2 (Formlabs; SLA)	2%
	3 (RS Pro; FDM)	9%
	4 (Objet; MultiJet)	4%
	5 (MakerBot Replicator 2; FDM)	9%
	6 (EOS; SLS)	73%

Table 3
Respondent answers to age category (Q12), gender (Q13), religion (Q15), highest level of education (Q16), and work history (Q17). Count of major religious identities reported by full survey respondents (following data cleaning), results with a count < 5 being grouped into 'other'. Work history with multiple responses accepted (* = responses >50%).

Question	Answer Choices	Responses	
Q12 Age in years	17 or younger	0%	2
	18–20	5%	22
	21–29	39%	168
	30–39	26%	113
	40–49	16%	68
	50–59	7%	31
	60 or older	6%	27
	Total	*100%*	*431*
Q13 Gender	Male	37%	158
	Female	60%	259
	Other	3%	14
	Total	*100%*	*431*
Q15 What religion do you identify with?	None	-	217
	Christianity	-	64
	Atheism	-	52
	Catholicism	-	23
	Agnosticism	-	12
	Christianity (Church of England)	-	11
	Judaism	-	8
	Islam	-	7
	(blank)	-	6
	Other	-	31
	Total	-	*431*
Q16 Highest level of education	Secondary	1%	5
	College/A-Level	7%	28
	University undergraduate	24%	105
	University post-graduate	45%	194
	Doctorate	21%	91
	Other (please specify)	2%	8
	Total	*100%*	*431*
Q17 Have you ever worked with any of the following? Please select all that apply.	Museum	38%	165
	Human remains/ deceased people	56%*	240
	Non-human bones/ remains	51%*	218
	Police/emergency services	13%	58
	Forensic science laboratory	16%	71
	Disaster recovery work	9%	38
	Armed forces	7%	31
	Legal system/courts	9%	40
	Medical/hospital organisations	28%	120
	Archaeological services	35%	152
	Virtual/3D models	32%	138
	3D printing	24%	105
	Research	60%*	258
	None of the above	13%	58
	Total	*393%*	*1692*

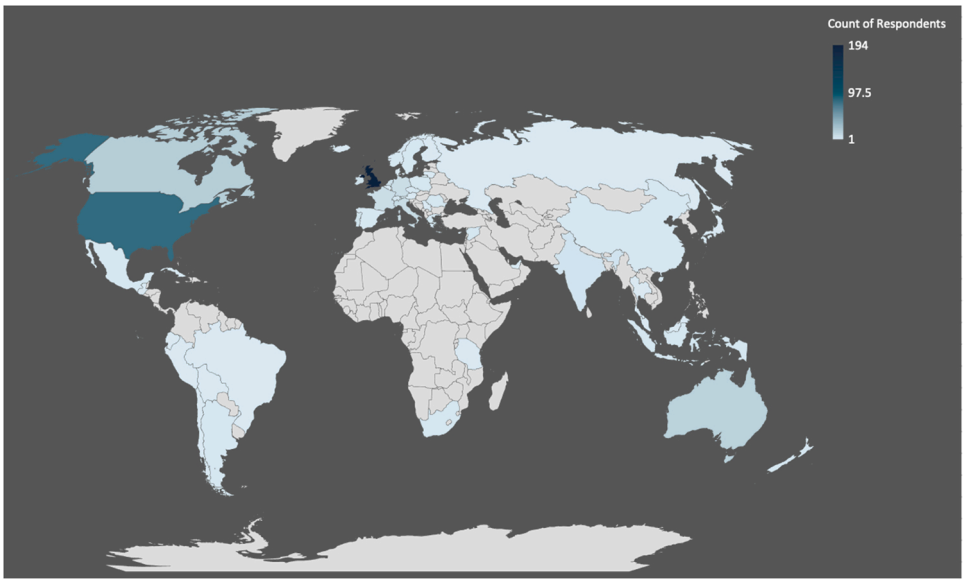

Fig. 1. Depiction of respondent answers to demographic nationality (Q14) (answered n = 431; not answered = 12). Additionally, n = 9 recorded as 'dual'.

printed representations of human remains, and 9% were unsure. This opinion was subsequently explored with follow up questions to understand if that opinion might alter given different considerations and contexts, and how these might affect the perception of the ethical considerations of using 3D prints in a courtroom.

3.2.2.1. Application. Question 19 revealed that more than 90% of respondents believed it is ethical to create 3D prints for scientific teaching, as evidence in court and for use in identification (more than 370 responses in each case) (Table 4). Additionally, 76% indicated that they believe it is ethical to create 3D prints for museums/public display (n = 313). The application 'for personal/decorative use' received a much less positive response, with 21% of respondents agreeing that application would be ethical (n = 87) (Table 4).

Question 20 revealed that 97% of total respondents agreed it was ethical to produce prints for diagnostic purposes, of these, and responses remained high (87–97%) for different manners of death (Table 5). 98% of total respondents agreed that it was ethical to produce prints for use as evidence in court, of these, 73% agreed this was ethical when the individual died naturally, compared with 100% who agreed this was ethical when the individual died suspiciously. 96% of total respondents agreed that it was ethical to produce prints for teaching, of these, a high proportion of 92–96% agreed this was ethical for each manner of death. A lower majority of total respondents (62%) agreed that it was ethical to produce prints for display, and of these, 70–71% agreed this was ethical when the individual died suspiciously or accidentally while a higher proportion (96%) agreed this was ethical when the individual died naturally. Only 4% of total respondents answered that prints would 'never' be considered ethical to produce. From the respondents that answered 'never', 44% (8 respondents) responded that this was the case when the decedent had died suspiciously, 67% (12 respondents) when the decedent died accidentally, and 89% (16 respondents) when the decedent died naturally (Table 5).

A high majority of respondents (94%) considered it ethical to produce a 3D print given that it may aid a conviction, a diagnosis or both (question 21). Only 6% responded that neither of these factors would affect their ethical decision-making. Responses to question 22 revealed that the majority of respondents (60%) replied that the avoidance of an autopsy would make them more likely to agree to 3D printing human remains, 22% replied 'no', and 18% replied that they were 'not sure'.

Table 4
Respondent answers to Q19, Q21, and Q22 (answered n = 410; not answered = 33). Q19 Multiple responses accepted.

Question	Answer Choices	Responses	
Q19 Is it ethical to create 3D printed representations of human remains for any of the following applications? (Select all that apply)	For display in museums/public	313	76%
	For personal/ decorative use	87	21%
	For medical/ scientific teaching	396	97%
	For use as evidence in court	397	97%
	For use in identification	372	91%
	None of the above	3	1%
Q21 Are you more likely to consider it ethical to produce a 3D print given that it may aid.	A conviction?	7%	28
	A diagnosis?	9%	37
	Both	78%	321
	Neither	6%	24
	Total	*100%*	*410*
Q22 Are you more likely to agree to 3D printing remains if in doing so it avoided an autopsy/invasive post-mortem examination?	Yes	60%	248
	No	22%	89
	Not sure	18%	73
	Total	*100%*	*410*

Table 5
Cross-tabulated responses to Q.20 reported by full survey respondents (total response count n = 1465). Reported as percentages (%) and count of each application, total response count for that application (shaded columns); and split into manner of death (unshaded). For example, total for considering it ethical for 'died naturally' (n = 346) divided by total for 'diagnostic purposes' (n = 397) results in 87%.

Application	Total	Died naturally e.g., from illness		Died suspiciously e. g., murder		Died accidentally e. g., vehicle collision	
For diagnostic purposes	97%	87%	346/ 397	97%	384/ 397	91%	360/ 397
For use as evidence in court	98%	73%	292/ 402	100%	400/ 402	91%	365/ 402
For teaching	96%	96%	379/ 394	90%	354/ 394	92%	362/ 394
For display	62%	96%	245/ 254	70%	178/ 254	71%	181/ 254
Never	4%	89%	16/18	44%	8/18	67%	12/18

3.2.2.2. Consent. To consider the topic of permissions and consent, question 23 asked whether permission should be sought from a next of kin or relative prior to 3D printing. A majority (63%) of respondents replied that permission should be sought, 31% replied only 'sometimes' and a minority of respondents (6%) replied that permission from the next of kin was 'never' required for 3D printing (Table 6). Question 24 subsequently asked if it was important to have a consent form to allow the 3D print to be produced. 64% of respondents replied that having a consent form was important, 14% disagreed, and 22% were unsure (Table 6).

3.2.2.3. Treatment. Question 25 revealed that 28% of respondents thought that 3D prints should be treated the same as human remains, 55% disagreed, and 17% were unsure.

Question 26 asked what should be done with a 3D print after being used in a court of law, and Question 27 asked whether the respondents thought that the next of kin should be informed/asked what to do with the print after use. The majority of respondents (56%) replied that 3D prints should be kept for research/teaching after use, while 17% replied that the prints should be recycled and 15% selected 'other' (Table 7). Exploration of the 'other' responses identified that 22 of the 59 responses mentioned that the print should be kept as part of the evidence archive, additionally, 26 of the 59 mentioned that the decision should be asked to the next of kin. This latter point being explored in the succeeding question. For Q27, 67% of respondents replied that 'yes', the next of kin should be asked what to do, 20% selected 'no', and 13% 'not sure'. Thus, reflecting the findings from the Q26, that the majority of the respondents value the wishes of the next of kin of the deceased, moreover, they believe that the next of kin should have some authority over this decision.

3.2.2.4. Distribution. Questions 28–32 explored the distribution of the printed remains, who owns the 3D print, and whether these can be shared online or in-person for various purposes. Question 28 asked who the print belongs to, with one answer selection possible from a range of potential owners. Between 17% and 20% of respondents thought that the 3D print either belonged to the deceased, the next of kin, the person who produced the print, or 'other' (Table 8). Many of the comments from the 'other' option noted that the owner of the print depended on who produced/commissioned the print, and that the specifics of the scenario would influence their opinion over who 'owned' the print.

Question 29 revealed that 8% of respondents replied that it is 'always' ethical for digital copies of the 3D model to be openly available online, 69% replied 'sometimes', and 23% replied 'never'. The majority of respondents could not definitively say whether the 3D model could be shared online to the general public. Question 30 asked whether it is ethical for digital copies of the 3D model to be available online to academics or scientists. In this scenario, 35% of respondents indicated that is 'always' ethical, 62% replied 'sometimes', and 3% replied 'never' (Table 9). This result reflects the opinion of Question 29, where respondents were unsure if this practice would be ethical, and it is likely that this would be affected by context.

Table 6
Respondent answers to Q23, and Q24 addressing issues of consent.

Question	Answer Choices	Responses	
Q23 Should permission be sought from a next of kin/relative prior to 3D printing?	Always, where possible	63%	255
	Sometimes	31%	126
	Never	6%	24
	Total	*100%*	*405*
Q24 Do you think it is important to have a consent form to allow the 3D print to be produced?	Yes	64%	260
	No	14%	57
	Not sure	22%	88
	Total	*100%*	*405*

Table 7
Respondent answers to Q26 addressing the treatment of 3D prints.

Question	Answer Choices	Responses	
Q26 If used in a court of law, **what do you think should be done with a 3D print afterwards?**	Disposal - general waste	1%	6
	Disposal - recycled	17%	69
	Kept for research/ teaching	56%	225
	Returned to family/ next of kin	6%	23
	Returned to remains (buried, cremated, etc.)	6%	23
	Other (please specify)	15%	59
	Total	*100%*	*405*

Table 8
Respondent answers to Q28 addressing the distribution of 3D prints.

Question	Answer Choices	Responses	
Q28 In your opinion, who does the print belong to?	Deceased	17%	69
	Next of kin	18%	72
	Doctor	0%	0
	Police	3%	13
	Scientist/Researcher	13%	51
	Court	10%	41
	Person who produced the print	20%	80
	Other (please specify)	20%	79
	Total	*100%*	*405*

Table 9
Respondent answers to responses to Q29, Q30, Q31, and Q32, addressing the distribution of 3D prints.

Question	Answer Choices	Responses	
Q29 Do you think it is ethical for digital copies of the 3D model to be available online to the general public?	Always	8%	32
	Sometimes	69%	278
	Never	23%	93
	Total	*100%*	*403*
Q30 Do you think it is ethical for digital copies of the 3D model to be available online to academics/scientists?	Always	34%	139
	Sometimes	63%	253
	Never	3%	11
	Total	*100%*	*403*
Q31 In your opinion, is it ethical to reproduce 3D prints for academics/researchers to use in teaching/research?	Always	41%	165
	Sometimes	58%	233
	Never	1%	5
	Total	100%	403
Q32 In your opinion, is it ethical to sell for profit 3D prints to academics/researchers for using teaching/research?	Always	7%	27
	Sometimes	46%	187
	Never	47%	189
	Total	*100%*	*403*

Question 31 subsequently asked if it is ethical to reproduce 3D prints for academics or researchers to use in teaching or research. 41% of respondents replied that is 'always' ethical to reproduce 3D prints for academia, 58% replied 'sometimes', and 1% replied 'never' (Table 9). This result indicated strong support for the production of prints for academic use. The final question towards distribution, question 32, asked whether it is ethical to sell for profit 3D prints to academics or researchers for use in teaching or research. A minority of 7% of respondents replied that is 'always' ethical to sell 3D prints for profit, 46% replied 'sometimes', and 46% replied 'never' (Table 9).

3.2.2.5. Courtroom Decision-Making. The final category of questions sought to explore the public perception of the use of 3D printed human remains in a courtroom, to gain insights as to whether this might affect decision making. The majority of respondents (73%) thought that it would be easier to understand an injury from a '3D print', < 1% (3

respondents) replied from a 'photograph', 12% were 'not sure', and 14% replied 'other' (question 33, Table 10). Many of the comments from the 'other' response answered that it 'depends on the injury'. Additionally, some thought that both the photograph and 3D print were needed together. There was a prevalent perception by the survey respondents to favour the use of a 3D print over a photograph. The results from this question strongly indicated that the 3D print was preferred as the visual courtroom aid.

To differentiate the 3D print as a tangible aid, question 34 then asked whether it would be better to have a visual aid or representation that you can physically handle. A high majority of respondents (88%) replied 'yes' (Table 10). As above, this result indicated a clear preference from the respondents for the 3D print as an aid in a courtroom.

The final question explored the use of 3D prints in court and asked whether there should be guidelines in place to ensure that practitioners are acting ethically with regards to 3D printing forensic injuries (question 35). A high majority of respondents (85%) agreed that there should 'always' be guidelines (Table 10).

3.2.2.6. Concerns. The final survey question, question 36, was an open text comment box asking if the respondent had 'any other concerns or comments?'. A wide variety of responses were received (n = 170). The responses were coded using descriptive and simultaneous coding, subsequently these codes were categorised into four overarching themes: blank/no comment; framework; application; and connection with deceased. The codes and a count of these are presented in Supplementary Information. Responses broadly addressed ethical good practice [39] (Table 11) or the application of the 3D print (including a consideration of the type of connection with the deceased a 3D print has) (Table 12).

4. Discussion

4.1. Survey data

The responses to the survey questions provide insights into the opinion of the respondents when considering the application, consent, treatment, courtroom decision-making, and distribution of 3D printed remains, as well as identifying additional concerns raised by respondents. Instances where response analysis relate to the nine ethical principles of anonymity, autonomy, beneficence, consent, context, justice, non-maleficence, proportionality, and transparency have been highlighted in the text below.

4.1.1. Application

Within this cohort of participants, it was generally considered to be ethical to use 3D prints as evidence in court (97% of participants). This concurs with the findings from Hirst et al. [18] and English Heritage [17], where responses were generally in favour of human remains or printed remains being displayed. However, the results from this study also showed that displaying remains may not always be considered ethical if 3D prints are created for uses other than courtroom use. For example, only 21% of respondents agreed that creating a 3D print for personal/decorative applications would be ethical (Table 4). This echoes the findings from Hirst et al. [18], who found that opinion varied when human remains were used for research compared with use for museum display. This distinction is important, as it signifies that while the respondents generally agree that printing remains is ethical, there are situations or applications where it is more ambiguous with a diversity of views in different **contexts**. Utilising prints 'for personal/decorative use' differs from other applications, as it is for 'personal' use, rather than what could be called 'for the greater good' and it is harder to argue for there being **beneficence** for the deceased. Conversely, in using a 3D print in as evidence in a court case, the print is contributing towards seeking **justice**, an important ethical principle.

Participants were strongly in favour of prints being produced for diagnostic purposes, for teaching, and for use as evidence in court and broadly agreed it was ethical to produce prints for court when the

Table 10
Respondent answers to responses to Questions 33–35, concerning the contribution of 3D prints to decision-making in the courtroom.

Question	Answer Choices	Responses	
Q33 Do you think it would be easier to understand an injury from a photograph or a 3D print?	Photograph	1%	3
	3D print	73%	291
	Not sure	12%	49
	Other (please specify)	14%	57
	Total	*100%*	*400*
Q34 Do you think it would be better to have a visual aid/representation that you can physically handle?	Yes	88%	353
	No	1%	5
	Not sure	11%	42
	Total	*100%*	*400*
Q35 Should there be guidelines in place to ensure practitioners are acting ethically with regards to 3D printing forensic injuries?	Always	85%	341
	Sometimes	13%	52
	Never	2%	7
	Total	*100%*	*400*

Table 11
A selection of open comments received by the full survey respondents grouped into the 'framework' category reflecting four ethical principles.

Ethical themes	Responses
Consent	*"I believe the question of the consent -or lack therefor- [sic] of the deceased is absolutely key and must definitely be addressed as consent is a pivotal aspect of 'ethics'."*
	"There are some instances where it would be necessary not just to get consent from the next of kin but also from the tribe or culture (egg [sic] Native Americans, Maoris, [sic] etc)."
Context	*"My answers assume an adult decedent. I think I would have answered differently for a child."*
Transparency	*"My concern is 3D scans can be altered and needs to adapted [sic] before printing. This process needs to be transparent and the skills of accuracy of the modeller proved before allowing the evidence in court."*
Justice	*"I think ultimately if it is for a 'greater good' by increasing the chance of a fair trial or successful conviction or aids in teaching then it is ethically acceptable"*

Table 12
A selection of open comments received by the full survey respondents grouped into the 'application' and 'connection with deceased' categories (copied verbatim).

Category	Responses
Application	*"The print should be respected as though it were the remains themselves."*
	"A 3D print - legally - does not symbolise a person as it is not a biological material."
	"Don't see any real difference between a 3D print, a photo, a drawing, painting or a verbal description."
	"Although directly related to the individual or deceased, the 3D print is not the person"
	"There are some instances where it would be necessary not just to get consent from the next of kin but also from the tribe or culture (eg [sic] Native Americans, Maoris, etc). It may be that different cultures have different views on these issues so it would be important to get input from people from a variety of different cultures. In some places, for example, you're not allowed to take photos because it's seen as stealing the person's soul."
Connection with deceased	*"It could be that especially non-medical trained people might more easily be convinced [sic] way or another."*
	"Strict guidelines should be in place."
	"I wonder if using the real bones would make a jury more or less "sympathetic" towards an injury, for example"
	"This could be a good alternative to examining remains when family members don't want the body to be examined directly."
	"It is unethical to make money from people's remains."

individual died suspiciously (Table 5). A key determining factor of whether the creation and use of a 3D print is ethical appears to be whether the 3D printed outcome is **beneficial** to society (i.e., in the pursuit of **justice**) in a similar manner to considerations in public health [42].

Fewer participants felt it would be ethical to produce prints for display purposes (62%). However, in instances when it was considered to be ethical to use prints for display, respondents were more in favour of this from individuals who died naturally (96%) in comparison to those who died suspiciously or accidentally (70–71%) (Table 5). This may be due to the consideration that suspicious or accidental death usually occurs suddenly, and it is therefore, less likely for **consent** to have been granted by the individual. In this **context**, it is difficult to know what the wishes of the deceased might have been and thus more difficult to respect the dignity of the deceased (as examined by Palop and Currás [43]). A majority of respondents also agreed that print production was more ethical if it avoided invasive autopsies (Table 4). This is another situation where if the production of a 3D print is **beneficial** to the deceased, respondents are more likely to consider this an ethical practice. In this situation, the print is contributing to preserving the dignity of the deceased by avoiding the need for invasive procedures. The intended use of 3D prints did appear to impact whether respondents felt the creation and use of the prints could be justified on ethical grounds.

4.1.2. Consent

A clear majority (94%) of respondents considered permission from the next of kin of the deceased to be an important factor when printing remains (Table 6). Likewise, many respondents (64%) stated that having a **consent** form was important. These results echo the considerations of gaining consent from living subjects, as discussed by Carew et al. [39] and Passalacqua and Pilloud [44], and gaining **consent** from cadaver donors [38,45]. Given the general perception that **consent** should be sought from the individual, there is a clear feeling from respondents that 3D prints are meaningfully linked to the deceased, and that their creation and use warrant ethical consideration. Indeed, the findings indicate that the **'consent'** aspect of producing and using prints was a key influencing factor in terms of what was considered to be ethically appropriate practice.

4.1.3. Treatment

The question of whether 3D prints should be considered as 'real' human remains appears to be a divisive issue, with just over half of respondents replying that 3D prints do not need to be treated the same as human remains in handling and storing (Table 7). These findings are in line with the results from Hirst et al. [18] who reported that approximately half of their respondents thought that 3D prints warranted less ethical requirements compared with physical human remains. This also reflects current dialogue that addresses 'dehumanising' remains in archaeological work [43,46]. In contrast there was more support for it being appropriate to ask the next of kin about what to do with a print after its use (Table 7), which is in accord with the Human Tissue Act [47] that calls for next of kin to be consulted on the disposal of human remains. This was further discussed by France [48] who recommends that the next of kin should receive **transparent** and truthful information.

These findings raise the question of whether **context** influences the degree to which 3D printed human remains should be treated with the same dignity and respect as 'real' human remains. In situations where models are created as part of distressing scenarios such as cases of murder or serious injury there may be a different threshold for their treatment in comparison to less emotive cases. There is also a question to be addressed about whether in general forensic 3D prints from anatomical specimens (which are from donated cadavers) should be treated the same as prints derived from archaeological specimens, which do not have any living next of kin.

4.1.4. Distribution

When considering the ownership of the print, there was a difference in opinion about whether the print should be considered to belong to the deceased or their next of kin, or the person who produced the print. The former position may be broadly predicated on the basis that the print is perceived to maintain a connection to the deceased (Table 8), in contrast to the latter position that suggests that the print becomes intellectual property (IP) reflecting the debate about whether remains are considered as art [38,39]. These results indicated that 3D prints may not always be perceived to be meaningfully linked to the deceased when it comes to handling and storing the print. The 'other' comments received for question 28 also offered additional insights, in particular that the **context** of the scenario is key to the consideration of who owns the print (see 3.3.4). The responses were varied and did not reveal one majority opinion.

Additionally, respondents were generally in favour of a 3D print being publicly shared online 'sometimes', indicating that there were differing perceptions of what would be ethically acceptable in this context (Table 9). However, when considering sharing the print online for researchers (question 30), or for researchers to use the print in teaching or research (Question 31), respondents were more positively in favour, this concurs with the results by Hirst et al. [18]. This distinction could be due to the higher ethical restrictions in place in academic research, or because the print may be **benefitting** society through research. However, these results are also likely to be influenced towards enabling research activities due to the demographic of the respondents, a high majority of whom held higher education degrees (Table 3).

4.1.5. Courtroom decision-making

There was a clear preference from respondents for using 3D prints over photographs as courtroom aids (Table 10). Less than 1% of respondents chose photographs as the preferred option for understanding injuries. These results align with the findings from Blau et al. [15] and Errickson et al. [16], that 3D prints are perceived to be more effective visual aids. A key factor in this choice appeared to be being able to physically handle the print which concurs with findings from Blau et al. [15] and Errickson et al. [16]. While it is known that showing 3D printed human remains in a courtroom can elicit an emotional response to those in court, the extent of this impact requires further research.

Respondents were also strongly in favour of having ethical guidelines for 3D printing remains (Table 10), supporting the call for guidelines from Smith and Hirst [34]. The public perception that guidelines are needed 'to ensure that practitioners are acting ethically with regards to 3D printing forensic injuries' may be due to the perception that the evidentiary value of the print needs to be protected, and that **transparency** is needed, so that it can effectively contribute to crime reconstructions and be deemed admissible evidence in court.

4.1.6. Concerns

Whether the 3D print should be treated 'the same as human remains' divided public opinion. For example, 13 respondents offered comments that indicated that they did not consider prints to be real remains, 10 respondents indicated that the prints should be considered in a similar way to photographs/MRI/radiographs etc, and six respondents indicated that they felt that prints were linked to the deceased/human remains. The lack of consensus was also found by Palop and Currás [43] when considering the 'dehumanising' of human remains. Similarly other free text comments indicated that respondents felt that if the prints were used for an application other than courtroom use (e.g., teaching or for commercial use), then this could be considered unethical. The **context** in which a 3D print was created and then what the print was used for were important considerations for respondents when considering what they perceived to be ethical practice (Table 11 and Table 12). It was striking that the principles of **transparency** and **non-maleficence** were consistently referred to indicating the importance of incorporating ethical principles in ethical good practice guidelines. Additionally,

comments highlighted the perception that there is a need for appropriate training of practitioners, for evidence to verify the accuracy of 3D prints and their effect in a courtroom, and the need for quality control (as discussed by Carew et al. [49]).

The importance of considering any next of kin and ensuring that they are aware of the production of a print in addition to being consulted about what happens to a print after its use (if appropriate) was raised by respondents. Three of these responses highlighted concerns about situations where the deceased is a member of an indigenous people group or culture and ensuring that there is due care taken to establish whether the production of a print can be considered culturally appropriate, in line with the call for digital archaeologists to include indigenous archaeologists and indigenous beliefs in ethical discussions to avoid a colonialist approach [50] and the guidance by BABAO to consider genealogical descendants [23]. These insights reaffirm the importance of treating all prints with dignity and respect for handling, storage, and presentation, as well as the need to consider the **context** of a case and to consider seeking **consent**.

4.2. Limitations and further work

It is acknowledged that the majority of the survey respondents held a higher education degree, and many had experience of working with human remains, non-human (animal) remains, or in research more broadly, which is likely to have influenced the beliefs that were shared. The insights from this study came from 400 individuals, but there is clearly scope to conduct a broader study to gather opinions from the public that may be more representative, such as studies of collective decision making, or case-based research such as post-verdict surveys which could offer further insights [1,51].

5. Conclusion

This study sought to explore the opinions of members of the public regarding the creation and use of 3D prints of human remains through the lens of nine key ethical principles. The findings from the public survey indicated that:

1. Respondents strongly supported using 3D prints in courtroom demonstrations.
2. 3D prints in courtroom demonstrations may help jurors to better understand expert testimony over photographs.
3. When considering the creation and use of prints, respondents were largely concerned with the context of the case (or background of how the remains were obtained) and whether consent had been obtained prior to use.
4. It was considered that 3D printed replicas should be treated the same as human remains by some individuals, highlighting the importance of acting with good ethical practice and treating 3D printed remains with dignity and respect

It is hoped that these findings offer valuable insights into the perception of the public regarding 3D prints of human remains, as an important strand of identifying parameters within which the creation and use of 3D prints is justifiable. What the public considers ethically appropriate practice for the deployment of 3D prints is clearly dynamic and evolving. Increasing the awareness of critical issues for society is an important part of the process of establishing guidelines and policies that address best practices for the creation and use of 3D printing human remains (Carew et al. forthcoming).

CRediT authorship contribution statement

Rachael M. Carew: Conceptualization; Data curation; Project administration; Formal analysis; Methodology; Writing - original draft; Writing - review & editing. **James French:** Conceptualization; Methodology; Supervision; Writing - review & editing. **Carolyn Rando:** Conceptualization; Methodology; Supervision; Writing - review & editing. **Ruth M. Morgan:** Conceptualization; Methodology; Supervision; Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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This research was considered by the UCL SCS Departmental Research Ethics Committee and deemed exempt from requiring ethics approval.

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