Forensic Science International 335 (2022) 111286

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Forensic examination of living persons in 3D models

Lena Benz[a,b], Garyfalia Ampanozi[c], Sabine Franckenberg[c,d], Federico Massini[a], Till Sieberth[c,e,*]

[a] University of Zurich, 8057 Zurich, Switzerland
[b] University of Bern, 3012 Bern, Switzerland
[c] Institute of Forensic Medicine, University of Zurich, Winterthurertrasse 190/52, 8057 Zurich, Switzerland
[d] Institute of Diagnostic and Interventional Radiology, University Hospital Zurich, 8091 Zurich, Switzerland
[e] 3D Zentrum Zürich, Institute of Forensic Medicine, Winterthurerstrasse 190/52, 8057 Zurich, Switzerland

ARTICLE INFO

Article history:
Received 12 November 2021
Received in revised form 23 March 2022
Accepted 25 March 2022
Available online 28 March 2022

Keywords:
Photogrammetry
3D reconstruction
Photobox
Clinical forensics

ABSTRACT

Physical injuries caused by interpersonal violence or accidents are usually documented with photographs. In addition to standard injury photography using 2D photographs, the Institute *INSTITUT NAME BLINDED FOR REVIEW* uses a Botspot Botscan ® multi-camera device (Photobox; Aniwaa Ltd, Berlin, Germany) that allows for 3D documentation of a subject. The Photobox contains 70 cameras positioned at different heights looking at a central platform. Within a fraction of a second, all cameras are activated and acquire the necessary images for 3D documentation. In previous studies by Michienzi et al. (2018), the geometric correctness of 3D documented injuries was analyzed. While their work concentrated solely on artificial injuries and their dimensions, the work presented in this study analyzes whether the Photobox allows for accurate medical interpretation of injuries, by forensic pathologists. To perform this analysis, 40 datasets of a variety of real cases were processed to 3D models. The created 3D models were then examined by forensic pathologists on 2D computer screens, and the findings were compared with the original reports. While the aim of this work was to assess whether examinations based on a 3D model allows comparable results to immediate examinations of the subject, the results showed that examinations based on a 3D model are 85% accurate when comparing with physical examinations. This indicates that 3D models allow for reasonably accurate interpretation, and it is possible that accuracy might increase with improved equipment and better trained personnel.

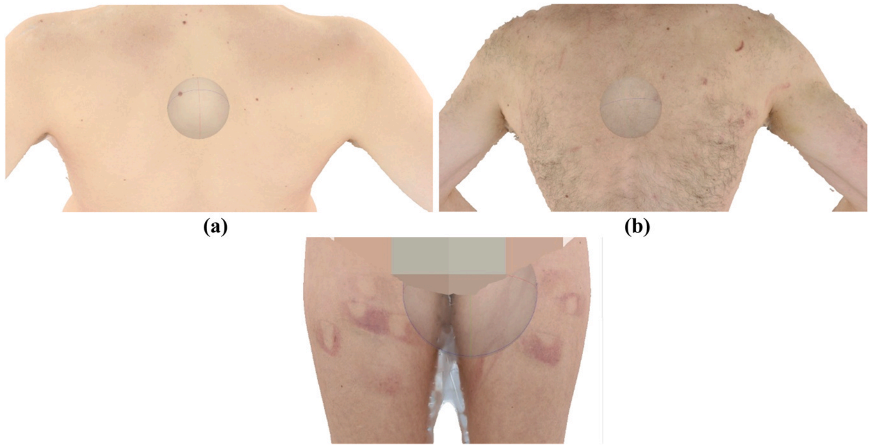
1. Introduction

The forensic documentation of injuries in cases of interpersonal violence or accidents includes detailed descriptions of the victim, injuries in written form, and drawn body sketches. These documents are usually supplemented with photographs taken with digital cameras (DSLR). To accurately document and photograph an injury, and therefore to preserve evidence for forensic purposes, a variety of instructions have to be followed. These instructions are based on a manual provided by the Swiss Association of Forensic Medicine [1].

The manual recommends documenting the situation before using tools or cleaning any soiling. Furthermore, it is necessary to start with a full-body photo before continuing with detailed photography following a logical procedure, such as top-to-bottom documentation [1]. The detailed photographs should contain a low-reflection scale positioned at the same depth as the medical finding to allow for size estimations of the injuries. The camera should also look orthogonally on the injury to allow for accurate documentation and subsequent visualization [1]. In addition, the camera settings must be appropriate, including exposure, white balancing, focus and other parameters that influence image quality. Despite following all of the rules, the documentation of 3D objects in 2D photographs will always lead to a loss of information or distortion of the subject due to the loss of depth information. This is why the Institute *INSTITUT NAME BLINDED FOR REVIEW* uses a Botspot Botscan (Botspot, Antiwaa Ltd.; Berlin, Germany) multicamera device (Photobox) in addition to 2D photographs. The multicamera device allows for whole-body 3D surface documentation using photogrammetry [2].

* Corresponding author at: Institute of Forensic Medicine, University of Zurich, Winterthurerstrasse 190/52, 8057 Zurich.
E-mail addresses: Lena.Benz@students.unibe.ch (L. Benz), Garyfalia.Ampanozi@irm.uzh.ch (G. Ampanozi), Sabine.Franckenberg@usz.ch (S. Franckenberg), Federico.Massini@uzh.ch (F. Massini), Till.Sieberth@irm.uzh.ch (T. Sieberth).

https://doi.org/10.1016/j.forsciint.2022.111286
0379-0738/



(c)

Fig. 1. Overview of different degrees and types of injuries. No injuries (a). A combination of a few sharp and blunt force injuries of different sizes (b). Many large intradermal blunt force injuries (c).

The advantages of 3D documentation are that the subject can be viewed as a whole, including injured and unscathed bodyparts, and it is comfortably accessible to different experts or to new questioning even later, guaranteeing quality control. Furthermore, representing body parts on a 3D reconstruction allows easy explanation to nonmedical experts such as lawyers. Errickson et al. showed that digital and analog 3D models provide better jurors' understanding and decision-making in court than do digital photographs [3]. Furthermore, 3D documentation has already been established in a variety of forensic applications for documenting crime scenes, relevant traces and objects [4,5]. These are a number of reasons that 3D images are useful in forensic examinations.

Photogrammetry is also used in other medical fields [6–9]. For example, in dental medicine, dynamic stereometry is used as a method to visualize the kinematics as well as the anatomy of the mandible and the temporomandibular joints by means of patient-specific 3D animation [10,11]. Additionally, photogrammetry is used in engineering, where it has been an accepted and important technology for several years [12]. Another field of application is road traffic accident reconstruction, where it is used to document incident sites for forensic reconstructions [4,5]. In general, photogrammetry represents a rapid, inexpensive and simple method for the 3D documentation of places and subjects. Furthermore, it only requires short documentation time, easily accessible equipment and short preparation time.

The study by Michienzi et al. utilized the Photobox to measure injury dimensions on a 3D model of a mannequin [13]. The obtained data were compared to standard 2D forensic photographs, while the gold standard was represented by measurements of the original artificial injury sticker. It was found that the 3D models allow for more accurate measurements in comparison with standard 2D photographs. This was shown not only for visualization of the 3D model on a 2D screen, but also for virtual reality [13,14]. Specifically, this means that the Photobox can replace standard 2D photography, at least for dimensional measurements. However, it was not determined whether the 3D models created by the Photobox allow for accurate medical interpretation of the injuries. A study by Massini et al. already looks at this topic [15]. Their study focused on different modalities of examination using 3D models by only using a mannequin with multiple injury stickers. These factors did not allow for depth evaluation of the injuries, and the difference between the smooth seamless surface of the mannequin presents a significant difference from human skin [15].

Considering the advantages of photogrammetric documentation and its prevalent use in forensics and medicine, its use should be evaluated not only for documentation purposes but also for examination in forensic medicine. The aim of our study is to compare the injury descriptions based on 3D photogrammetric reconstructions with in situ examinations of living persons, analyzing whether injuries can be perceived correctly on 3D models with an accuracy comparable to a live examination.

2. Material and methods

Data were selected from our case archive, processed into 3D replicas, and then examined by board-certified forensic pathologists in dedicated software. In this section, we explain the selection criteria, recording and processing of the acquired data.

2.1. Case selection

2.1.1. Inclusion criteria

For data selection, the cases had to fulfill several criteria. The cases needed to provide both data from the in situ examination and Photobox data acquired at the time of the examination. The Photobox has been in use since 2018, limiting the time frame to 2018–2020. As the Photobox is a stationary device, only cases examined at the location of the Photobox were be considered.

2.1.2. Exclusion criteria

Exclusion criteria included cases where the person was hospitalized or examined at an external examination site. To test our method as broadly as possible, we decided to select injuries that varied in number and severity to represent the full range of injuries occurring in a forensic pathologist's daily routine [16]. Based on this, five different categories were established:

Category 1: persons without any injuries (Fig. 1(a)).

Category 2: persons with scars.

Category 3: persons with hematomas, abrasions (Fig. 1(b)).

Category 4: persons with lacerations, stab wounds.

Category 5: persons with many and large injuries of any type (Fig. 1(c)).

We selected eight cases per category, which led to 40 cases in total being examined, including all their injuries. Each of the four forensic pathologists then examined two cases per category. Accordingly, 10 cases were examined per forensic pathologist. This setup allowed for comparability between the examiners and cases, excluding ability bias.

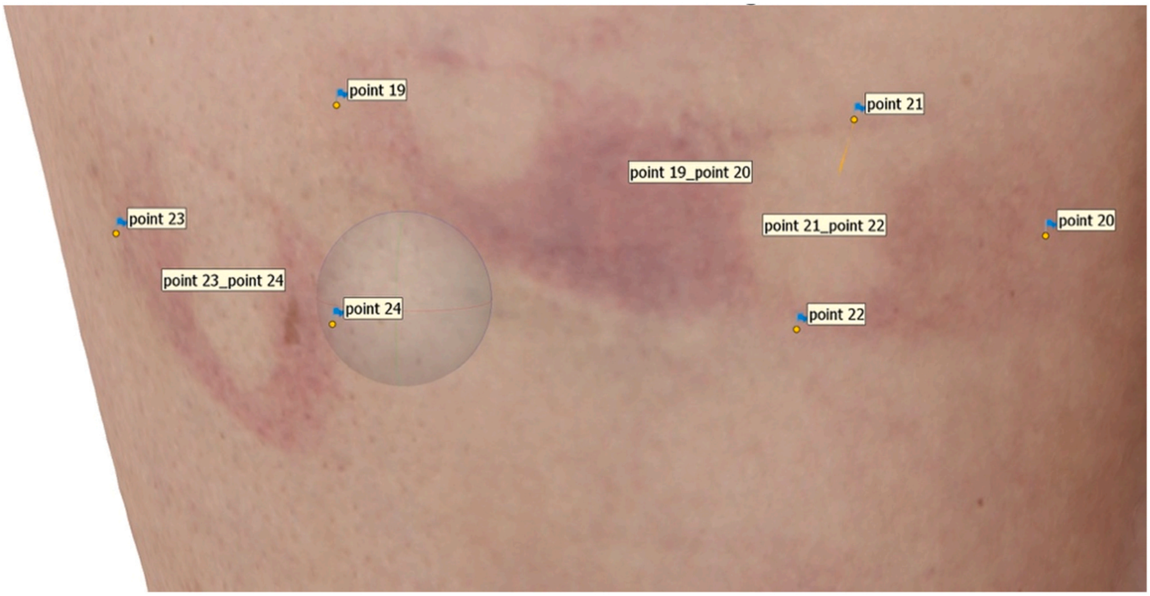


Fig. 2. Size measurement within the Agisoft Metashape Professional. The points mark the start and end points chosen by the examiner, while the connection line between those points represents the injury measurement. This connection line is not visible, as it is a rounded surface, and the straight connection between the points is behind the surface, which means that the size measured is a measurement of the 2D projection of the injury.

2.2. Data recording

The photogrammetric device used in this study relied on multi-camera photogrammetry. The Photobox contains 70 DSLR cameras that are arranged around a center. All cameras can be activated simultaneously, acquiring high-resolution images within a fraction of a second. This arrangement allows a 360° recording of a subject who stands on the central platform in the cylindrical chamber. For forensic documentation, the subject should have their hands at their hips and their feet shoulder width apart to allow visibility of all relevant areas. The dress code was in accordance with the recommendations of the Swiss Forensic Pathology Association [17]. In case of injuries to the legs, additional stepping positions are used to allow for documentation between the legs. The obtained data then enables us to build a 3D reconstruction of the subject using dedicated photogrammetric software. Compared to handheld DSLR cameras, the Photobox is more time efficient and minimizes human error on both image quality and visual detection of forensically relevant findings [2]. The Photobox is also equipped with rulers, providing an accurate scale allowing for accurate measurements on the 3D model [18,19].

2.3. Data processing

The datasets were then processed with *Agisoft Metashape Professional* software (version 1.6.1 build 10003 (64 bit); St Petersburg, Russia) to generate 3D models with the quality settings on high. In between the processing steps, noise and clutter present in the models had to be removed manually to allow for acceptable 3D models. The final surface model was then smoothed before applying a texture with four times 4096 × 4096 pixel textures. In the final step, the scale was implemented by measuring points of known distance. This was performed with all 40 subjects, including their stepping positions if available. Examination of the created 3D models was also performed in *Agisoft Metashape Professional.* The software allows rotation, translation and zooming of the 3D models to allow a detailed and unhindered view of the model and the injuries from any point of view. Furthermore, the software provided tools to measure dimensions on the 3D model (Fig. 2).

2.4. Read-out

Readout was performed by two residents in forensic pathology and two board-certified forensic pathologists with varying years of experience. The forensic pathologists performed the examination of the cases allotted to them on a computer screen. It was ensured that the cases were unknown to the forensic pathologist to ensure a blinded, unbiased examination. Anonymized information on the circumstances of the incident was provided according to the original report, allowing for similar examination conditions between the in situ and 3D models.

2.5. Statistical analysis

The reports of the 40 cases examined on the 3D model were compared to the original in situ reports, which were considered the gold standard. The reports are usually written by residents under supervision of board-certified forensic pathologists. To compare both reports, we focused on a list of features that are used to describe injuries, including *wound orientation, wound shape, wound color, wound size, wound edges and forms of violence*. The reported injuries were displayed tabularly with the above-described features as subunits (compare appendix, Table 1). To avoid forensic pathologists using different words for the same description, they received a list of words to choose from. This allowed for a better comparison of the examination findings and therefore a more precise analysis of the examination success on the 3D model.

The injury descriptors, *wound orientation, wound shape, wound color, wound edges and forms of violence,* were compared if the

Table 1
Average match of each examiners description of an injury with the original examination.

	Including Injury Size	Excluding Injury Size	Number of Injuries
Examiner 1	78%	86%	42
Examiner 2	73%	82%	40
Examiner 3	76%	88%	57
Examiner 4	75%	83%	43
	76%	**85%**	**182**

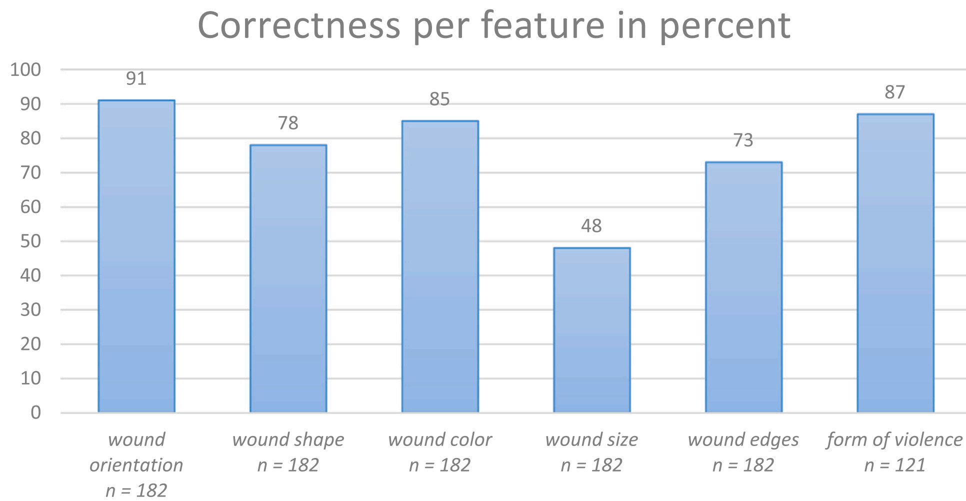


Fig. 3. Match of injury description between original examination and 3D examination per feature in percent.

description made was the same between the original examination and the 3D examination. If both reports used the same description, then it was considered a match; if the description was different or a finding in the 3D report was not described, then it was counted as fail. If a finding was not described in the original report but was described in the 3D report, we did not take it into account. This was often the case for the feature *form of violence,* which was not specified in the original report.

The *wound size* feature was a special case. The *wound sizes* used for the in- situ report were usually based on scale measurements to the examiner's hand, and were therefore somewhat rather inconsistent, while the *wound size* in the 3D examination was measured on the 3D surface using precise tools in the software. The measurement made was then compared with the *wound size* stated in the original report. If both were equal or varied by +/- 20%, it was considered a match.

All matches were summed per injury to individually evaluate the correctness in situ of each examined injury. In total 182 skin injuries were examined.

Furthermore, it was analyzed whether there were differences between the match rates of the 4 forensic pathologists according to the individual features.

3. Results

The analysis of the gold standard in situ examination compared to the reports of the 3D examination over all 182 injuries, with five to six features each, resulted in 1031 comparisons in total.

Between the four forensic pathologists, the match rate was between 73% and 78% with all six features (Table 1). On average, 76% matched between 3D examination and the gold standard. However, the *wound size* measurements made on the 3D model often did not match the hand-measured sizes made in the in situ reports. When considering all features except the *wound size,* the match rate increased to 85%.

When evaluating the features individually, it was found that the features ranged between 91% for *wound orientation* of the injury to 73% regarding the *wound* edge description, while the size dropped to only 48% correctness (Fig. 3).

When analyzing the results regarding *wound shapes and edges* more closely, we can see that the congruence was quite variable between the four forensic pathologists (Fig. 4). *Wound orientation*, *wound color* and *form of violence* were constant between the forensic pathologists, with the exception of examiner two for the form of violence.

4. Discussion

Our aim was to compare the injury descriptions based on 3D photogrammetric reconstructions with in situ examinations of living persons. In detail, we analyzed whether injuries can be accurately perceived, interpreted and evaluated on 3D models as they can be on real living subjects.

When analyzing our data, it was noticeable that the feature of *wound size* performed the worst, with only 48% congruence over all forensic pathologists. This discrepancy, despite the consideration of 20% variation, can be explained by the different methods used to establish the *wound size* of an injury. While the examination of the 3D model uses measurement tools based on mathematical procedures, the *wound sizes* in the original in situ reports were measured by hand using scales next to the injury on the living subject or next to the injury on the photograph. In particular, these later methods measure the projected length of the injury rather than the total length of an injury. This discrepancy is mostly due to there being no standard of measurement for the total length or the projected length of an injury. However, past studies with a focus and study setup on *wound size* measurements by Michienzi et al., Koller et al. and Sieberth et al. showed that measurements on 3D Photobox models allow for more accurate measurements than do estimations based on 2D forensic photography [13,14,19]. This is also confirmed by studies in other fields that show that photogrammetry can be used for accurate and precise measurements [20]. Nevertheless, in this study, the original reports were considered the gold standard, and therefore, the measured *wound sizes* had to be considered incorrect. This led to a congruence value of 76%. However, if these measurements would have been excluded, the congruence in total of all subgroups summed up would be 85%.

The presented results show that there is a difference in congruence between the four forensic examiners, especially according to *wound shapes and edges*. Therefore, according to those two subgroups, congruence not only seems to be method-dependent but also dependent on the forensic pathologist. For example, the fourth forensic pathologist was above average in describing *wound shape* but below average in describing *wound edges*. This variability somehow explains some incongruence. The feature of *form of violence* was often not described by Examiner No. 2, who did not want to or could not determine this for any reason. This led to some incongruence with this feature compared with the results of the other examiners.

One major limitation of this study is that the forensic pathologists evaluating the 3D model had a defined list of terminology to

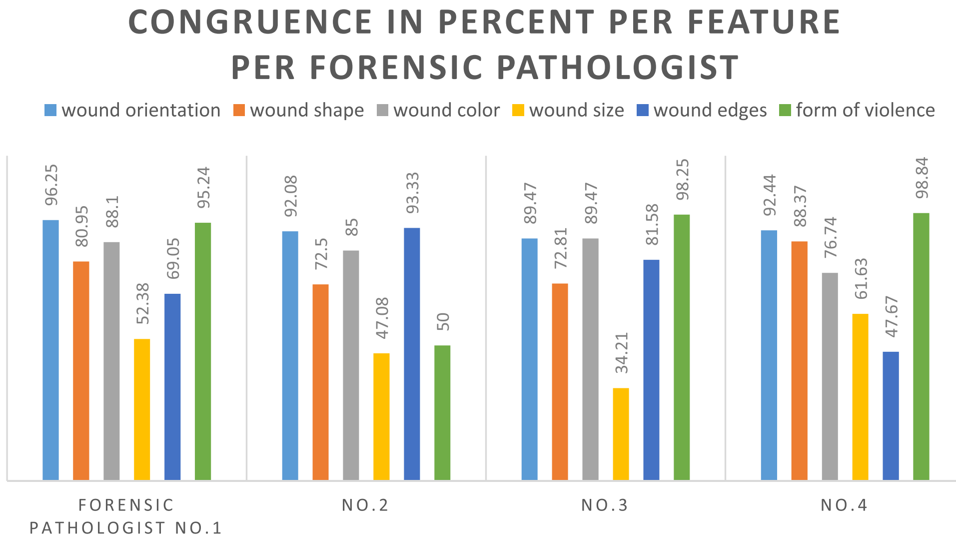


Fig. 4. Congruence between original examination and examination on the 3D model in percent per feature per pathologist.

choose from, compared with the forensic pathologists in situ who wrote the original report without limiting their vocabulary. Descriptions then had to be evaluated as incongruent despite the possibility that the same description was meant by both examiners who simply used different words. Furthermore, if there was an injury described in the 3D report but a description of it was missing in the original report, then we could not consider it correct, although it would be clearly visible and might have been missing in an original report. Additionally, not all forensic pathologists favor technology-centered approaches, not only because they require time to learn, but also because they require a novel working approach. This might have led to a lack of motivation while examining the 3D model and might have negatively influenced the outcome. Nevertheless, the evaluation of the original reports showed that swelling was often not perceived on the 3D model. This could be because forensic pathologists were not familiar with the software and did not rotate the 3D model several times, as would be necessary to assess swelling accurately.

In addition to the human limitation factor, there were also some technical limitations; for example, it is not possible to assess the mouth, eyelids, genitalia or areas covered by hair. Additionally, the creation of 3D models out of 70 images requires additional knowledge of the software, and therefore requires technical staff for data processing as well as maintaining suitable hardware. Furthermore, it required an additional person to perform the scan procedure and anamnesis.

On the other hand, there are many advantages to documenting and evaluating injuries with a 3D model. First, it allows for fast and thorough documentation of the complete person with all visible injuries. This allows for future evaluation by other forensic pathologists or for addressing other forensic questions that might arise during ongoing investigations. The data can be easily stored and evaluated years later if necessary, representing a digital copy of the whole patient and not just partial photographs. This might be beneficial for the time-consuming judicial procedure, which can take up to several years. This allows for a prolonged sustainment of judgment or even more objective judgment [3]. Nonetheless, the reports based on the given feature descriptors were made in detail, and they were often more detailed than the original reports.

The analysis of our data has shown that the evaluation on 3D models, with its 85% match rate, meets our expectations of being comparable to the original direct evaluation and appears to be very promising. We imagine that it should soon be possible to perform a clinical forensic examination using the Photobox system instead of requiring a forensic pathologist to be on duty to perform the examination, which could instead be performed by a forensic nurse [21–23]. As a medically trained professional, they would be able to perform anamnesis, collect evidence and perform the scan with the Photobox. After successful examination, the data could be passed on to a forensic pathologist who could check the data and formulate a report.

In conjunction with the results found by Massini et al., it is also possible to predict that 3D models can be viewed not only on a screen but also in other visualization modalities such as virtual reality [15]. This allows for other forensic approaches, for example, incident reconstruction [24].

5. Conclusion

The comparison between examinations based on a 3D model and immediate examination of the subject led to 85% congruence. The results appear to be very promising that 3D documentation can be used as a tool for whole body documentation and examination in forensics. Injury description based on a 3D model is a good method for the evaluation and presentation of forensic data. Limitations in the study design explain some incongruence. In summary, an examination based on a 3D model allows for comparable results to an immediate physical examination, and it has many advantages that recommend it to routine clinical use.

Funding

This research did not receive any funding.

Ethics

Our study does not fall within the scope of human research law. This was confirmed by the Ethics Commission of the Canton of Zurich: Req-2020-00702.

CRediT authorship contribution statement

Lena Benz: Data processing and realization of project, Manuscript. **Garyfalia Ampanozi:** Manuscript, Concept and Supervision. **Sabine Frankenberg:** Data acquisition, Manuscript. **Federico Massini:** Concept, Data acquisition. **Till Sieberth:** Concept development, Supervision, Idea, Manuscript, Data processing.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors express their gratitude toward Emma-Louise Kessler, MD, for her generous donation to the Zurich Institute of Forensic Medicine, University of Zurich, Switzerland.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.forsciint.2022.111286.

References

[1] Sgrm.ch, 2021. ⟨https://www.sgrm.ch/inhalte/Forensische-Medizin/Forensische_Fotodokumentation_Final_01.pdf⟩, (Accessed 2 March 2021).
[2] A. Leipner, R. Baumeister, M. Thali, M. Braun, E. Dobler, L. Ebert, Multi-camera system for 3D forensic documentation, Forensic Sci. Int. 261 (2016).
[3] D. Errickson, H. Fawcett, T. Thompson, A. Campbell, The effect of different imaging techniques for the visualisation of evidence in court on jury comprehension, Int. J. Leg. Med. 134 (2019).
[4] M. Thali, M. Braun, W. Brüschweiler, R. Dirnhofer, Matching tire tracks on the head using forensic photogrammetry, Forensic Sci. Int. 113 (2000).
[5] U. Buck, K. Buße, L. Campana, F. Gummel, C. Schyma, C. Jackowski, What happened before the run over? Morphometric 3D reconstruction, Forensic Sci. Int. 306 (2020).
[6] V. Stuani, R. Ferreira, G. Manfredi, M. Cardoso, A. Sant'Ana, Photogrammetry as an alternative for acquiring digital dental models: a proof of concept, Med. Hypotheses 128 (2019).
[7] J. Leal, R. Aroeira, V. Gressler, M. Greco, A. Pertence, J. Lamounier, Accuracy of photogrammetry for detecting adolescent idiopathic scoliosis progression, Spine J. 19 (2019).
[8] A. De Benedictis, E. Nocerino, F. Menna, F. Remondino, M. Barbareschi, U. Rozzanigo, F. Corsini, E. Olivetti, C. Marras, F. Chioffi, P. Avesani, S. Sarubbo, Photogrammetry of the human brain: a novel method for three-dimensional quantitative exploration of the structural connectivity in neurosurgery and neurosciences, World Neurosurg. 115 (2018).
[9] H. Mitchell, Applications of digital photogrammetry to medical investigations, ISPRS J. Photogramm. Remote Sens. 50 (1995).
[10] D. Ettlin, L. Gallo, B. Berg, Das Kiefergelenk in Funktion und Dysfunktion, Thieme, 2019.
[11] Validity and Reliability Evaluation of Data Acquisition Using Vectra 3D Compare to Direct Method, Ieeexplore.ieee.org, 2021. ⟨https://ieeexplore.ieee.org/stamp/redirect.jsp?arnumber=/6490105/6498007/06498016.pdf⟩, (Accessed 5 August 2021).
[12] A. Pilar Valerga Puerta, R. Aletheia Jimenez-Rodriguez, S. Fernandez-Vidal, Raul, S. Fernandez-Vidal, Photogrammetry as an engineering design tool, Prod. Des. (2020).
[13] R. Michienzi, S. Meier, L. Ebert, R. Martinez, T. Sieberth, Comparison of forensic photo-documentation to a photogrammetric solution using the multi-camera system "Botscan", Forensic Sci. Int. 288 (2018).
[14] S. Koller, L. Ebert, R. Martinez, T. Sieberth, Using virtual reality for forensic examinations of injuries, Forensic Sci. Int. 295 (2019).
[15] F. Massini, L. Ebert, G. Ampanozi, S. Franckenberg, L. Benz, T. Sieberth, Comparison of superficial wound documentation using 2D forensic photography, 3D photogrammetry, Botscan© and VR with real-life examination, Forensic Sci. Med. Pathol. 17 (2021).
[16] C. Birngruber, G. Lasczkowski, R. Dettmeyer, Forensische Verletzungskunde, Springer, Berlin, Heidelberg, 2020.
[17] Gesellschaft für Rechtsmedizin, Die forensisch-klinische Untersuchung von Personen nach Gewalteinwirkung, 2015.
[18] K. Kraus, Photogrammetry, second ed., De Gruyter, Berlin, 2007.
[19] T. Sieberth, L. Ebert, S. Gentile, B. Fliss, Clinical forensic height measurements on injured people using a multi camera device for 3D documentation, Forensic Sci. Med. Pathol. 16 (2020).
[20] I. Barbero-García, R. Pierdicca, M. Paolanti, A. Felicetti, J. Lerma, Combining machine learning and close-range photogrammetry for infant's head 3D measurement: a smartphone-based solution, Measurement 182 (2021).
[21] K. Berishaj, C. Boyland, K. Reinink, V. Lynch, Forensic nurse hospitalist: the comprehensive role of the forensic nurse in a hospital setting, J. Emerg. Nurs. 46 (2020).
[22] C. Toon, K. Gurusamy, Forensic nurse examiners versus doctors for the forensic examination of rape and sexual assault complainants: a systematic review, Campbell Syst. Rev. 10 (2014).
[23] C. Peternelj-Taylor, T. Bode, Have you read your forensic nursing: scope and standards of practice? J. Forensic Nurs. 6 (2010).
[24] T. Sieberth, A. Dobay, R. Affolter, L. Ebert, A toolbox for the rapid prototyping of crime scene reconstructions in virtual reality, Forensic Sci. Int. 305 (2019).