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TECHNICAL NOTE

PATHOLOGY/BIOLOGY

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Photogrammetric Documentation of Regions of Interest at Autopsy—A Pilot Study*

ABSTRACT: In this pilot study, the authors tested whether photogrammetry can replace or supplement physical measurements made during autopsies and, based on such measurements, whether virtual computer models may be applicable in forensic reconstructions. Photogrammetric and physical measurements of markers denoting wounds on five volunteers were compared. Virtual models of the volunteers were made, and the precision of the markers' locations on the models was tested. Twelve of 13 mean differences between photogrammetric and physical measurements were below 1 cm, which indicates that the photogrammetric method has a high accuracy. The precision of the markers' location on the models was somewhat less, although the method is still promising and potentially superior to the current procedures used for reconstructions. The possibility to measure any distance on a body, even after the autopsy is concluded and the corpse is no longer available, is one of the biggest benefits of photogrammetry.

KEYWORDS: forensic science, forensic pathology, photogrammetry, wound documentation, human body model, reconstruction

During an autopsy, pathologic findings and areas of interest are described and photographed. Such documentation is important as it may assist in criminal or other investigations (1). Normally, the size and location of these sites are recorded metrically. Locations are usually recorded as distance from a fixed anatomical point using some form of physical scale. In some cases, the police may inquire about the distance from a wound to other fixed points rather than the ones used during the autopsy. These questions may be asked long after the autopsy has been concluded because new evidence has appeared. As the corpse may have been cremated or buried, these questions are then difficult to answer confidently. In this pilot study, the authors test whether photogrammetry allows a precise measurement of wounds based on the photographs of a corpse during its autopsy. Furthermore, given that measurements of the wounds are made digitally, the authors explored the feasibility of producing a virtual model of a corpse with wounds, which can then virtually be placed in specific body positions, for example the position of the victim's body when the wounds were inflicted. Thereby, the position of the wounds, coupled with other forensic evidence such as the angle of a wound from a projectile or a knife, can be analyzed and various scenarios be recreated. The aim of the study was therefore to compare physical and photogrammetric measurements of the location of wounds and to evaluate the precision of the wounds' locations on a virtual model.

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Background

Wounds on a victim may be measured with photogrammetry if one has photographs, taken with a calibrated camera, from different sides and angles of the victim. The photogrammetric measurements are made by ordinary vector calculation in a 3D model generated from the photographs. Photogrammetry [using the software PhotoModeler® (2)] is already routine at the authors' unit for identifying perpetrators seen on CCTV (3,4) and has also been used in a study of facial image identification (5). However, most of the previous studies regarding autopsy room photogrammetry have included a step of photographing the object by projecting a light pattern onto it to make a 3D surface model (6–15). The authors wanted to test a simpler methodology with only one set of ordinary digital photographs without the light pattern, and therefore also without a surface model.

A virtual model of a corpse with wounds can be made with the computer software Poser® (16), based on the photogrammetric measurements. Poser® contains humanlike models that consist of segments such as a waist, a hip, thighs and shins and may be used to create characters for computer games. All segments are ordered hierarchically, with the hip as the parent segment, and may be adjusted in size and moved in relation to their parent segment. Limitations may be applied to the models' joints to avoid unnatural positions. The software uses inverse and forward kinematics for posing (17). Poser® has previously been used in forensic studies (18), among others for a virtual reconstruction of a gunshot-trauma (1). Furthermore, it has been used in a study where the biomechanics were analyzed in situations of injuries to the anterior cruciate ligament (19).

Methods

Photographs of five male volunteer study subjects were taken with a Canon 350D camera (3456 × 2304 pixels) equipped with a 17-mm lens. The camera had been calibrated in PhotoModeler® with 12 photographs of an 80 × 80 cm calibration sheet. All subjects were dressed in black shorts and had four markers placed on each of their bodies, which represented wounds (Fig. 1). The subject lay in a supine position on the floor, and coded targets were placed around him. In order to be able to perform the measurements true to scale, the software must ascertain specific distances and angles, which was done by including the coded targets in the photographs; the coded targets allow the software to reproduce a correct scale. Eight photographs were taken in 360 degrees around the subject with the handheld calibrated camera and a flash. To reproduce the position of the subjects' ribs, the photographs were all taken at the end of an exhale phase. A distance between two coded targets was recorded and later used to add a scale to the model. The locations of the markers were measured with a folding ruler. The physical and the photogrammetric measurements were compared, and a mean difference for each distance was calculated. The exact length of an edge of a solid, straight object in the photographs was always included as a control.

The same five study subjects were then photographed standing up and sitting down on a box. Eight photographs of each body position were taken as described above. The subjects had markers on the same locations as in the supine position, but in this part of the project, the focus was on marker A and B. There were markers on the study subjects' joints in addition to the markers that represented wounds. The purpose of these markers was to guide the operator when the Poser® model was adjusted. Coded targets were again placed around the subject to facilitate camera orientation.

A matching virtual model for each subject was made in Poser®. The model was made from one of Posers® built-in virtual models ("Ryan"). The photographs of the subject in the supine position were imported to the software where the model was adjusted to match the photographs. The operator started adjusting the pelvis and then worked distally with the torso and the legs, etc. Photographs from different directions of the study subject were used until the best fit of the model was reached, as estimated by the operator. A white ball (selected from the Poser® library) was placed on the same location as marker A and at the lower end of marker B (from now on referred to as marker 1 and 2) (Fig. 2). Thereafter, the distance from the left heel to marker 1 and from the right heel to marker 2 was measured. The models were then placed in the two other photographed positions: standing up and sitting down. The vertical distance from a horizontal plane through the foot soles to the

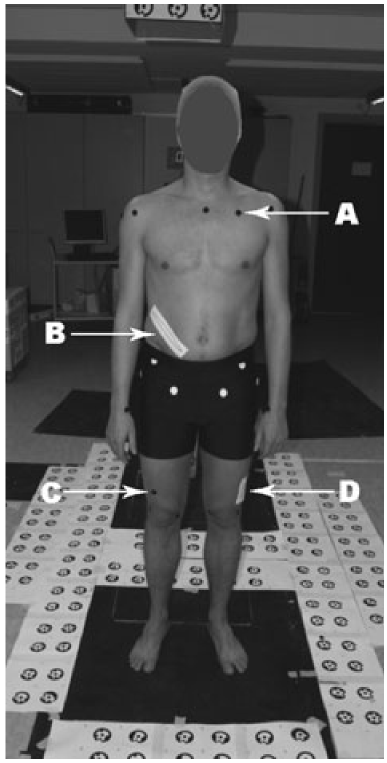

FIG. 1—*The locations of the four markers (A–D) on the study subject.*

FIG. 2—*The Poser® model is matched with the study subject's anthropometry in the background picture and a marker is placed on the left side of the chest (marker 1).*

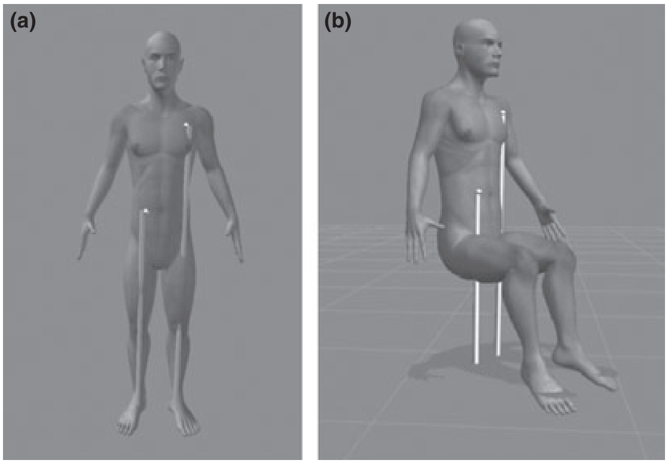

FIG. 3—*The Poser® model in the (a) standing-up and (b) sitting-down position with cylinders measuring the distances from the floor to marker 1 and 2.*

markers in the two new positions was measured (Fig. 3 *a,b*). Finally, the photogrammetric measurements and the measurements in Poser® of the markers' locations were compared.

Measuring in Poser®

Poser® does not have an integrated ruler. Therefore, a cylinder was selected from the Poser®-library and decreased to 10% of its original size in x- and z-scale. The cylinder was placed like a vector between the two points the authors wanted to measure and increased in y-scale until it matched the distance between these points. The cylinder measurement was specified in percent of its original y-scale. The length of the cylinder in the supine position was set to be the same as the photogrammetric measurement, and the following relationship was used to translate the length of the cylinder in the other two positions to centimeters:

$$\frac{M_{newposition}}{M_{supineposition}} = \frac{C_{newposition}}{C_{supineposition}} \text{ and}$$
$$M_{newposition} = M_{supineposition} \cdot \frac{C_{newposition}}{C_{supineposition}}$$

$M_{\text{new position}}$ was the unknown vertical measurement in centimeter from the floor to the marker in the standing-up or sitting-down position, which the authors wanted to compare with the photogrammetric measurement. $M_{\text{supine position}}$ was the photogrammetric measurement in centimeter from the heel to the marker in the supine position. $C_{\text{new position}}$ was the length of the cylinder in cylinder units from the floor (the horizontal plane through the foot soles) to the marker in the standing-up or sitting-down position and $C_{\text{supine position}}$ was the length of the cylinder in cylinder units from the heel to the marker in the supine position.

PhotoModeler® and Poser® have been used because the authors have experience with these software packages, but the methods presented are not software specific.

Results

As mentioned above, eight photographs were taken of the subject lying down, and all eight photographs were included in the photogrammetric analyses. The mean differences between the measurements by ruler and by photogrammetry are presented in Table 1. Twelve of 13 mean differences were below 1 cm, and eight of 13 mean differences were 1.5% or lower of the mean measurement. (To further control for the accuracy, the authors included measurements of an edge on a solid, straight object in the photographs. The largest error was 0.3 cm or <0.4%.)

The locations of marker A and B on the study subjects (measured by photogrammetry) were compared with the locations of marker 1 and 2 on the Poser® models (measured in Poser®) in the standing-up and sitting-down position (Table 2A,B). All Poser® measurements in the standing-up position have an error below 5%, and eight of the 10 differences are below 5 cm. In the sitting-down position, half of the measurements have an error below 5%, while the rest of the measurement errors range from 5.9% to 7.2%. Eight of the 10 differences are below 5 cm. The authors calculated that a difference of 1% in the Poser® cylinder would generate a difference of about 0.7 cm in the measurement.

Discussion

The aim of this pilot project was to investigate whether photogrammetry can replace or supplement physical measuring during autopsies. The focus has been on measuring wounds, but the methods presented may also be used with other regions of interest. During the autopsies in the authors' institute, the locations of wounds are measured with a nonflexible metal ruler with a centimeter scale (no scale for millimeters). This implies that an accuracy of measuring wounds of ±1 cm is acceptable. Indeed, the mean difference between ruler-based and photogrammetry-based measurements was below 1 cm in almost all the cases. However, physical ruler-based measurements are not necessarily a gold standard. There are inaccuracies when something is

TABLE 1—*The difference between the photogrammetric and the folding rule measurements.*

Distances*	Mean Measurement† (cm)	Mean Difference‡ (cm)	Mean Difference (% of Mean Measurement)
A1	147.2	0.2	0.1
A2	9.3	0.0	0.0
A3	13.3	−0.5	−3.8
B1	109.1	0.4	0.4
B2	118.6	−0.3	−0.3
B3	6.7	−0.1	−1.5
B4	13.7	0.0	0.0
B5	12.7	−0.6	−4.7
C1	61.3	1.1	1.8
C2	12.2	−0.2	−1.6
D1	59.7	0.6	1.0
D2	65.0	−0.1	−0.2
D3	5.0	−0.2	−4.0

*A1, From the left heel to the center of marker A; A2, From the mid-line to the center of marker A; A3, From the center of the left nipple to the center of marker A; B1, From the right heel to the lower end of marker B; B2, From the right heel to the upper end of marker B; B3, From the mid-line to the lower end of marker B; B4, From the mid-line to the upper end of marker B; B5, From the upper to the lower end of marker B; C1, From the right heel to the center of marker C; C2, From a marker placed lateral of the right knee to the center of marker C; D1, From the left heel to the lower end of marker D; D2, From the left heel to the upper end of marker D; D3, From the upper to the lower end of marker D.

†The average of the photogrammetric and the folding rule measurements for each distance.

‡The average of the differences between the folding rule measurement and the photogrammetric measurement.

TABLE 2—*The measurements made in Poser® compared with the photogrammetric measurements in the standing-up position (A) and sitting-down position (B).*

	Study Subject	Photogrammetric Measurement (cm)	Poser® Measurement (cm)	Difference (cm)	Difference (%)
		(A) Standing Up			
Marker 1	1	151.7	156.0	4.3	2.8
	2	136.0	137.3	1.3	1.0
	3	140.6	144.7	4.1	2.9
	4	142.4	148.4	6.0	4.2
	5	140.6	145.7	5.1	3.6
Marker 2	1	110.9	114.2	3.3	3.0
	2	100.5	102.1	1.6	1.6
	3	104.8	106.1	1.3	1.2
	4	109.0	112.1	3.1	2.8
	5	104.8	105.5	0.7	0.7
		(B) Sitting Down			
Marker 1	1	112.5	115.2	2.7	2.4
	2	98.5	105.6	7.1	7.2
	3	103.0	104.0	1.0	1.0
	4	106.9	107.6	0.7	0.7
	5	104.1	103.2	−0.9	−0.9
Marker 2	1	75.2	79.6	4.4	5.9
	2	67.0	71.8	4.8	7.2
	3	69.7	65.3	−4.4	−6.3
	4	75.6	72.6	−3.0	−4.0
	5	71.1	66.0	−5.1	−7.2

measured manually: First, it may be difficult to hold the ruler steady and fixed on the measuring points. Second, if the object is irregularly shaped (like a human body), then the ruler will not rest on the object during the measuring. In photogrammetry, the distances measured are calculated directly between 3D coordinates, for example in the photogrammetric 3D model, the coordinate that represents that the heel is located under the foot at the center of the heel, but when manually measuring from this point with the ruler in this study, the ruler was held on the lateral side of the leg with one end at the bottom of the heel. Thus, the ruler-based and photogrammetry-based measurements are not completely comparable; that is, some differences should be expected. The main advantage of photogrammetry is not greater precision by itself, but the ability to redo or take new measurements at a later stage if photographs have been secured. Such a scenario could, for example, be cases with many cut or stab wounds. In these cases, much time is dedicated to measuring, describing, and documenting the wounds. With photogrammetry, a number of photographs could quickly be taken (maybe even simultaneously from several cameras installed in the room), and the forensic medical doctor could immediately proceed with the autopsy. Furthermore, the wounds would never have to be touched during the documentation procedure, which decreases the risk of modifying them. If the police at a later stage wishes to have specific distance measurements to other body parts, which were not made around the time of the autopsy, these can always be made, even if the corpse is no longer available. This is also an economic and fast method, easily implemented, requiring only a digital camera and the photogrammetric software.

This pilot study focused on measuring wounds in a photogrammetric model of one side of the body. Photogrammetry may be used to calculate the angle of a wound from a projectile that has penetrated through the body. This may be done by making a photogrammetric model that includes both the front and the back of the victim's body. Theoretically, this may be done by including reference points from the sides of the body, visible both on photographs of the supine and prone position which can then be used to merge the two photogrammetric models, although a problem might be that body segments are not aligned in the same way in a prone and in a supine position. Also, it would be interesting to couple the external wound photogrammetry with postmortem CT-scanning. More work is needed to address this.

This pilot study is made on living subjects. Movements of the subjects, for example breathing or small movements of the limbs, may have influenced the accuracy of the photogrammetric measurements. Conversely, corpses may have an altered muscle tone and changed bodily contours (especially abdominally) due to decomposition. While probably negligible, these sources of error also would need to be further investigated.

An advantage of photogrammetry would be to enable better reconstructions, so as to better analyze the body stance when wounds were inflicted. Once the model had been adjusted, it was easy to use the Poser® software tools as many times as necessary for making reconstructions of different poses. There was some error when comparing distances from specific body points to wounds as measured by photogrammetry and in Poser®. However, this error has to be compared with how questions concerning the body stance and wounds are now answered. Typically, the police may ask what the distance from the ground to a wound in the chest could be if the victim, for example, had been standing erect, slumped or perhaps kneeling, given that a certain heel-to-wound distance has been measured during the autopsy (with the corpse in a supine position). Currently, without photogrammetry and virtual posing, an approximation can perhaps be obtained using a life-size dummy, or by estimating such distances on one or more individuals of more or less same height and body proportions.

There is a possible source of error when the markers are measured with the Poser® cylinder. The Poser® cylinder is placed like a vector between either the floor and the marker or the heels and the marker. The study subjects' foot soles in the sitting-down position were not placed horizontally. The floor was therefore defined as an imaginary plane through the center of the foot soles in both the photographs and the virtual models. The unit of the Poser® cylinder (percent in relation to its original size) is an integer. In some cases, the Poser® cylinder was either too short or too long and the exact length could not be achieved. In these cases, it was up to the operator to judge which of the two lengths was the best match. This also has an effect on the result, although it is small. There is also a problem with projecting a 3D model on to a 2D photograph of a person, and it can be difficult to assess the segments in- and out-translation. The in- and out-translation is the position of a segment moved in to or out of the photograph (for example, the abduction of the hip in a photograph taken from the side of the person). The authors found it difficult to assess the rotation of the femur and the size of the torso compared with the part of the torso in the back of the picture. The method of projecting a 3D object on to a photograph of a person is similar to one of the methods used for measuring body-height of people in surveillance images (20,21). Finally, error is introduced by incorrect placement of the joint markers. Still, Krosshaug and Bahr (22) found a model-based image-matching technique for reconstruction of human motion from video sequences, and they used Poser® in a way similar to this project. Their method has later been used to estimate joint-angles in situations of injuries to the anterior cruciate ligament (19).

Conclusion

The aim of this study was to investigate whether photogrammetry could replace or supplement physical measurements made during autopsies and to study the feasibility of using virtual Poser® models in forensic reconstruction. Twelve of 13 mean differences between photogrammetric and physical measurements were below 1 cm. The possibility to measure any distance on a corpse even after the autopsy is concluded would be one of the biggest benefits of photogrammetry. If markers placed on the corpse are visible during a CT- or MRI-scan, it may be possible to combine the scanning imagery with the photogrammetric model (14,15) and maybe also with the Poser® model. Finally, measurements obtained digitally may be used for virtual body-posing and thus lead to better recreation of body poses when the wounds were inflicted. Although the precision was somewhat less, and more studies and perhaps better operator training are needed, it is still thought to be promising, and potentially much superior to the procedures currently used. With newer technologies being used at the forensic institutes, such as high-resolution digital cameras and CT- and MRI-imaging, it would be very useful to calibrate the cameras so that they later can be used for accurate measuring in software such as PhotoModeler® and Poser® when needed. It is important to continue studying how photogrammetry and subsequent reconstructions may be used in forensic medicine to improve the quality of forensic documentation.

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