CASE REPORT

Alexander Pilin,[1] M.D., Ph.D.; František Pudil,[2] ing., Ph.D.; Josef Hořejš,[3] M.D.; and J. Braný,[4] Bc.

Determination of the Size of a Foreign Body in the Eye Using Image Analysis of Its Roentgenogram*

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ABSTRACT: The case of a computer-enhanced image analysis of X-ray pictures of a pellet in the orbit of a man who sustained a shotgun injury to his right eyeball is presented. The man was shot accidentally during a pheasant hunt. Two hunters were shooting simultaneously but they were using three different sizes of pellet—3.0, 3.5 and 4.0 mm. One of the pellets hit a third man in the eye. He sustained serious injury with a resultant loss of sight in this eye despite immediate medical treatment. Unfortunately the pellet could not be removed from the orbit, but it was necessary to establish who was responsible for the injury. The problem lay in determining the specification and size of the pellet at that moment. The problem was solved using computer-enhanced video image analysis of the X-ray pictures of the pellets. The image processor LUCIA G (http//www.lim.cz) was used.

KEYWORDS: forensic science, forensic pathology, shotgun injury, eye, foreign body, pellet size, X-ray, image analysis

Hunting is the common pursuit of many people, providing a release for their hunting instincts or just simply providing a form of mental and physical relaxation during their stay in nature. Despite the many safety precautions that exist, a lot of firearm injuries occur every year that result in serious harm to the health of individuals. Usually these occurrences are purely accidental, but responsible huntsmen must be accountable at the very least from the point of view of injury compensation. The job of investigator is made easier when the bullet is available for examination (e.g., in the case of through-and-through injury) or can be removed during medical treatment.

However, problems may arise when the offending projectile cannot be obtained or extracted and it remains embedded in the body. In such cases we have to somehow render it visible. X-ray examination is the main method in these cases (1,2). We present the study case of a computer-enhanced image analysis of roentgenogram of a pellet in the orbit of a man who sustained a shotgun injury to his right eyeball. The man was accidentally shot during a pheasant hunt. Two hunters shot at virtually the same time but they shot pellets of three different sizes: 3.0, 3.5 and 4.0 mm from the same manufacturer. The first hunter shot twice using 3.5 mm pellet size; the second hunter also shot twice but with a different pellet size—3.0 and 4.0 mm. A third man remained some 50 m from the hunting area but unfortunately one of the pellets hit him in the eye. He sustained a serious perforating injury to the eye and despite immediate medical treatment lost the sight of this eye. The pellet could not be removed from the orbital space. The problem arose in determining the exact size of the pellet so as to establish which of the two marksmen was responsible for the injury even though it occurred accidentally.

Methods

X-ray as well as computerized tomography (CT) examination was carried out immediately after the injury was sustained and both proved the existence of an oval foreign body with metallic density lodged in his right orbit. The need to establish the exact size of this foreign body was not considered at this time, so no special procedures were undertaken. Simple measurement revealed the foreign body to be approximately 4 mm in size. This approximate measurement was not accurate enough to determine which of the three possible types of pellet was lodged in the orbit. It must be again emphasized that a difference of only 0.5 mm had to be distinguished. The identification of the pellet was accomplished in two steps:

1. conventional X-ray examination, and
2. image analysis of the roentgenogram.

First Step

We asked the manufacturer of the pellets to provide us with samples of the pellets in question (basic set of standard pellets) so that we were be able to perform comparison and calibration. The manufacturer guaranteed that the difference in dimension of the pellets sizing of 3.0 mm, 3.5 mm and 4.0 mm would not be greater than $\pm$ 0.125 mm (tolerance $\pm$ 0.125 mm).

[1] Expert in Forensic Medicine, Institute of Forensic Medicine, University Hospital in Prague, Studnickova 4, 128 00 Praha 2, Czech Republic.
[2] Assistant in the Department of Food Analysis, Institute of Chemical Technology, Technicka 6, 160 00 Praha 6, Czech Republic.
[3] Deputy Chief in the Department of Radiology, Radiodiagnostic Clinic, University Hospital in Prague, U Nemocnice 2, 128 00 Praha 2, Czech Republic.
[4] Police investigator, Police of the Czech Republic—District Bureau of Investigation, Pribam, Czech Republic.
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The injured man was reexamined by X-ray after a forensic opinion was ordered. This revealed a pellet-like object in his right orbit on the postero-anterior (PA) and lateral picture of the skull (Fig. 1). Very small deformation—flattening—of the pellet could be seen on the lateral picture on its upper right quadrant. The distance tube-to-film was 110 cm and it was constant.

The distance of the pellet in the orbit from the X-ray unit table was measured from the edges of the skull in the frontal (on the lateral projection) and temporal plane (on the AP projection) and it was 6 cm. Then this approximate distance was controlled using the magnification factor. The magnification factor (M_f) was counted for different tube-to-object distances and the dimensions of the reference pellets (3.0 mm; 3.5 mm; 4.0 mm) were multiplied by it. Then the tube-to-object distance that matched best the size of the pellet from the roentgenogram (approximately 4.0 mm) was found. The film-to-surface distance of the X-ray table unit was 8 cm. The distance of the object from the table was calculated from the equation:

$$\text{distance tube-to-film} - (\text{distance tube-to-object} + \text{distance film-to-table})$$

that is, $110 - (96 + 8) = 6$ (Table 1). In this way we determined the distance from where the reference pellets were placed on the translucent material laid on the surface of the X-ray unit table.

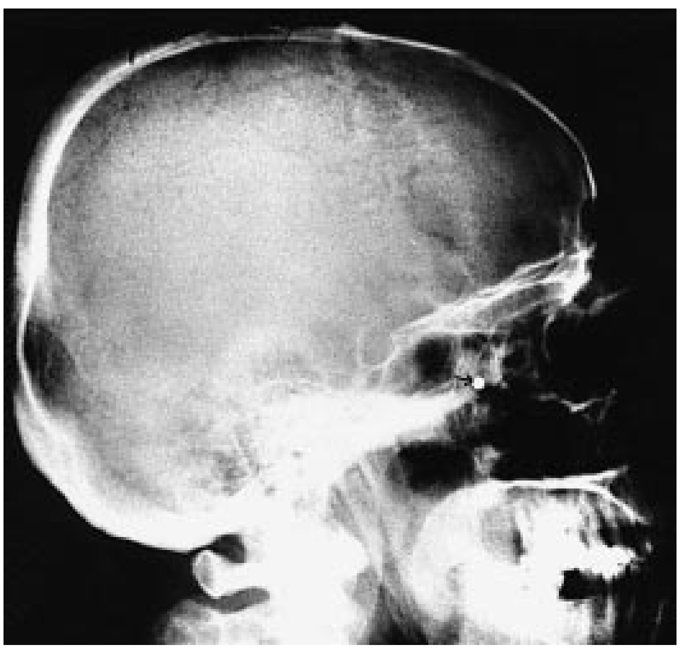

FIG. 1—*Pellet in orbit (arrow).*

Then the X-ray was performed. Thus we obtained a ''calibrated roentgenogram of standard pellets.'' The X-ray equipment was the Televix II (General Electric); the film used was, Fuji Super HRG, exposition 40 kV, 120 mA, 80 ms, with a secondary Bucky grid. The film was automatically developed.

Second Step: Image Analysis of X-Ray Picture

The basic set of standard pellets (direct video image), calibrated roentgenogram of standard pellets, and roentgenogram of the pellet in the orbit were recorded using a Hitachi HV C-20 video camera and then transferred to the computer. All recorded objects were processed by the method of image analysis using a suitable personal computer equipped with Lucia G image analysis software (Laboratory Imaging s.r.o, Prague), Version 3.2. The background of the pictures was thresholded and the dimensions of the pellets were evaluated from the inverted binary picture. Usual morphometric parameters were evaluated (3,4,5).

Results

The basic set of standard pellets (100 pieces in each size grouping) were analyzed as before. The aim of this investigation was to prove whether or not differences in the dimensions tolerated by the manufacturer exceeded the range of one size group; i.e., that no pellet from the 3.5 mm group fell within the group of pellets of size 4.0 mm. Figures 2 and 3 document that no pellet exceeded its group. The second reason was to determine the circularity of the pellets as a measure of their possible future deformity. The measured circularity remained virtually constant (Table 2). The usual morphometric parameters are mentioned in the tables, and they are commonly used in image analysis. For example: parameter ''area'' means the principal criterion. If noncalibrated, it means the number of pixels; if calibrated, it expresses the real size (4). The values of measured morphometric parameters such as diameter, width, length, and minimum and maximum Ferret diameters were almost identical. Thus only the diameter and width were used for determining the pellet's size. The roentgenogram of the pellet in the orbit and of the standard calibrating pellets (from X-ray film) were processed the same way. Values of the morphometric parameters obtained are given in Table 3. It is evident that the values of the parameters of the pellet from the orbit correspond best to the values of the calibrating pellets measuring 3.5 mm.

These results were further verified using a different procedure. It was observed that there were strips over the X-ray picture created by the Bucky secondary grid. The Bucky grid is a device consisting of lead strips of the same width, and the image of these strips can be seen on the roentgenogram at higher magnification. The Bucky grid is placed between the bottom of the table of an X-ray unit and the film, and its distance from the tube is constant. The object is above the grid. Under the condition of constant tube-to-grid-to-film distance, its image does not change. We counted the number

TABLE 1—*Calculation of object-to-table distance.*

Tube-to-Film Distance (cm)	Tube-to-Object Distance (cm)	Magnification Factor (M_f)	Pellet Dimension × M_f			Film-to-Table Distance	Object-to-Table Distance
			3.0 mm	3.5 mm	4.0 mm		
110	97.0	1.134	3.4	3.97	4.54	8	5
110	96.5	1.140	3.42	3.99	4.56	8	5.5
110	96.0	1.146	3.44	4.01	4.58	8	6
110	95.5	1.152	3.46	4.03	4.61	8	6.5

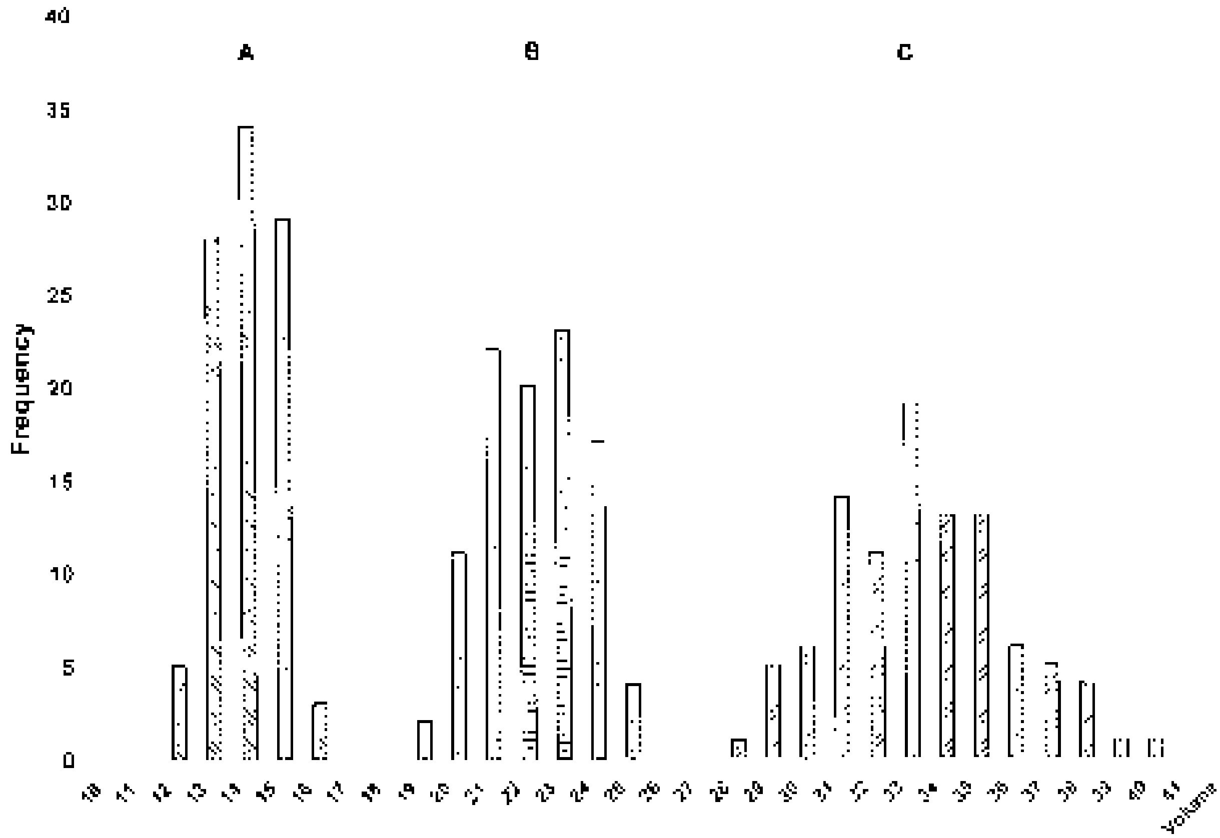

FIG. 2—*Histogram of frequency of volume of pellets in group with diameters: (*a*) 3.0 mm, (*b*) 3.5 mm, and (*c*) 4.0 mm.*

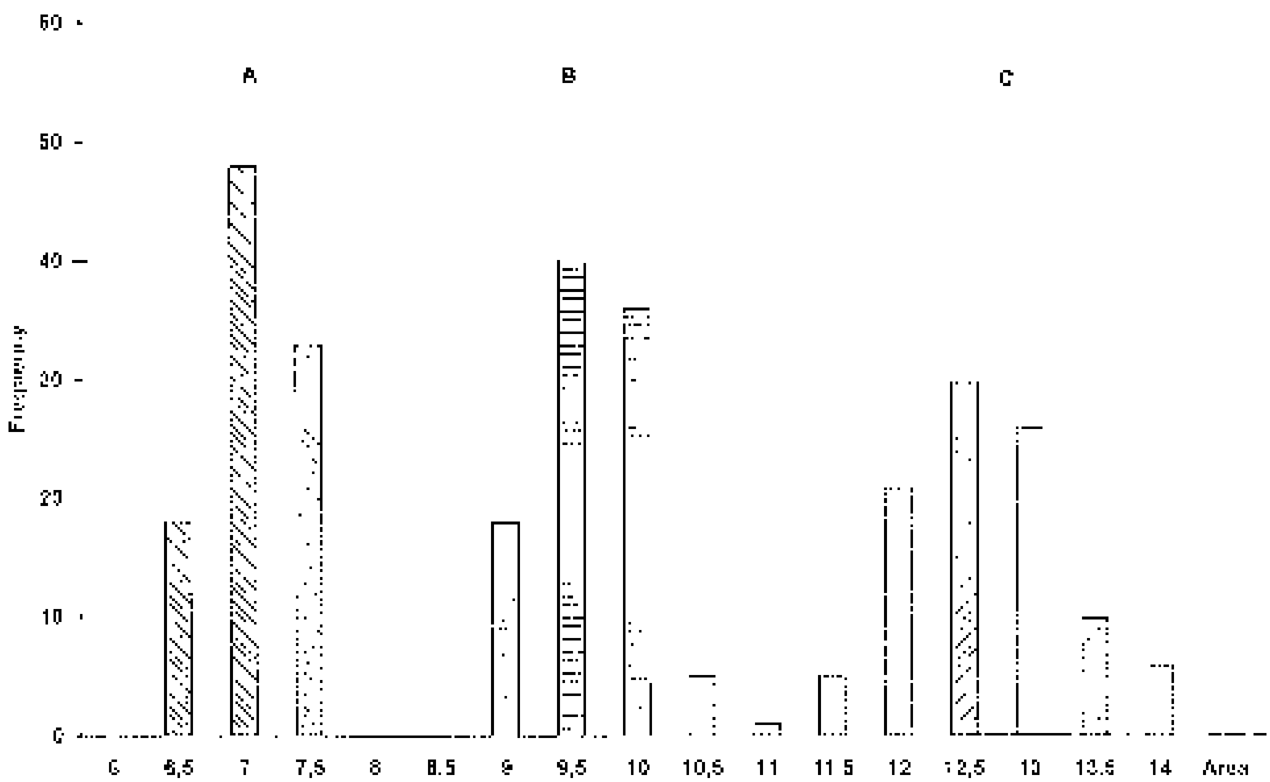

FIG. 3—*Histogram of frequency of area of pellets in group with diameters: (*a*) 3.0 mm, (*b*) 3.5 mm, and (*c*) 4.0 mm.*

of strips on the X-ray picture of the pellet in the orbit and compared this with the number of strips on the X-ray pictures of the calibrating pellets. The object 3 mm in diameter corresponded to 13 light strips, the object 3.5 mm in diameter corresponded to 16 light strips, and the object 4 mm in diameter corresponded to 18 light strips. It was found that the pellet in the orbit had the same number of strips as the pellet measuring 3.5 mm (Figs. 4 and 5). Due to secondary radiation their contours are uneven and make direct measurement of their width incorrect. Therefore we consider counting the number of strips reliable enough for this alternative procedure.

In this way we were able to determine that the hunter who shot the 3.5 mm pellet was responsible for the injury.

Discussion

The image analysis was used in this case because it was necessary to find out the real sizes of objects which differ 0.5 mm ± 0.125 mm. Image analysis is a very suitable method for such cases where multiple small objects have to be measured and to prove whether or not their dimensions exceed the range of one of the size groups.

The finding of a foreign body in human tissue is not uncommon. Depending on its material composition it can be visualized using conventional X-ray, CT, or magnetic resonance (MR) imaging (6). CT examination is the method of choice and it could have then performed. However, examination of a great number of slices 1 mm

TABLE 2—*Values of morphometric parameters obtained by direct video image analysis of standard calibrating pellets.*

Pellet	Area	EqDiameter	Volume	Perimeter	Width	Circularity
4.0 mm	12.39 ± 0.62	**3.97 ± 0.099**	32.83 ± 2.48	12.76 ± 0.36	**3.88 ± 0.09**	0.96 ± 0.02
3.5 mm	9.40 ± 0.41	**3.49 ± 0.076**	21.69 ± 1.42	11.13 ± 0.26	**3.38 ± 0.08**	0.95 ± 0.02
3.0 mm	6.83 ± 0.3	**2.95 ± 0.07**	13.44 ± 0.89	9.49 ± 0.23	**2.89 ± 0.07**	0.96 ± 0.02

TABLE 3—*Values of morphometric parameters obtained by image analysis of X-ray picture of pellet in the orbit and X-ray picture of standard calibrating pellets.*

	Area	EqDiameter	Volume	Perimeter	Width	Circularity
Pellet from PA projection	11.49	3.81	29.3	12.26	3.75	0.96
Pellet from lateral projection	**12.66**	**3.98**	**33.9**	**12.64**	**4.01**	**0.99**
Pellet 4 mm	16.35 ± 0.33	4.56 ± 0.06	49.74 ± 1.49	14.32 ± 0.18	4.56 ± 0.06	0.99 ± 0.01
Pellet 3.5 mm	**12.57 ± 0.67**	**4.00 ± 0.05**	**33.58 ± 2.59**	**12.61 ± 0.39**	**3.98 ± 0.11**	**0.98 ± 0.017**
Pellet 3 mm	9.34 ± 0.31	3.42 ± 0.06	21.52 ± 1.06	10.78 ± 0.2	3.46 ± 0.07	0.99 ± 0.009

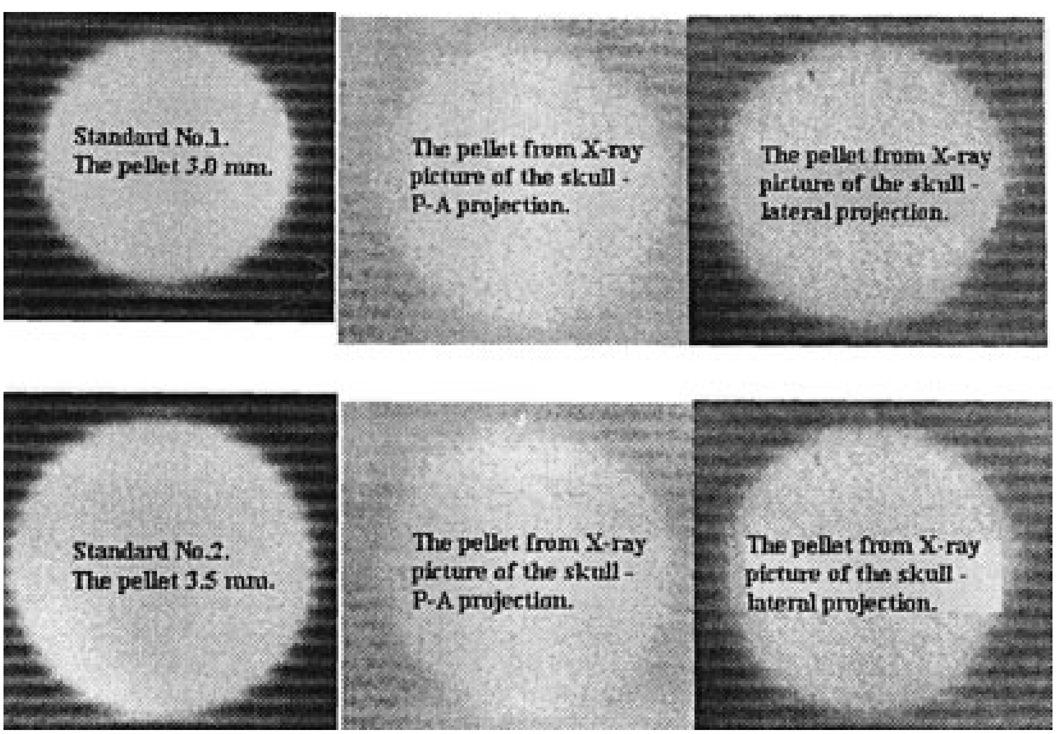

FIG. 4—*Comparison of dimensions of pellets from X-ray pictures.*

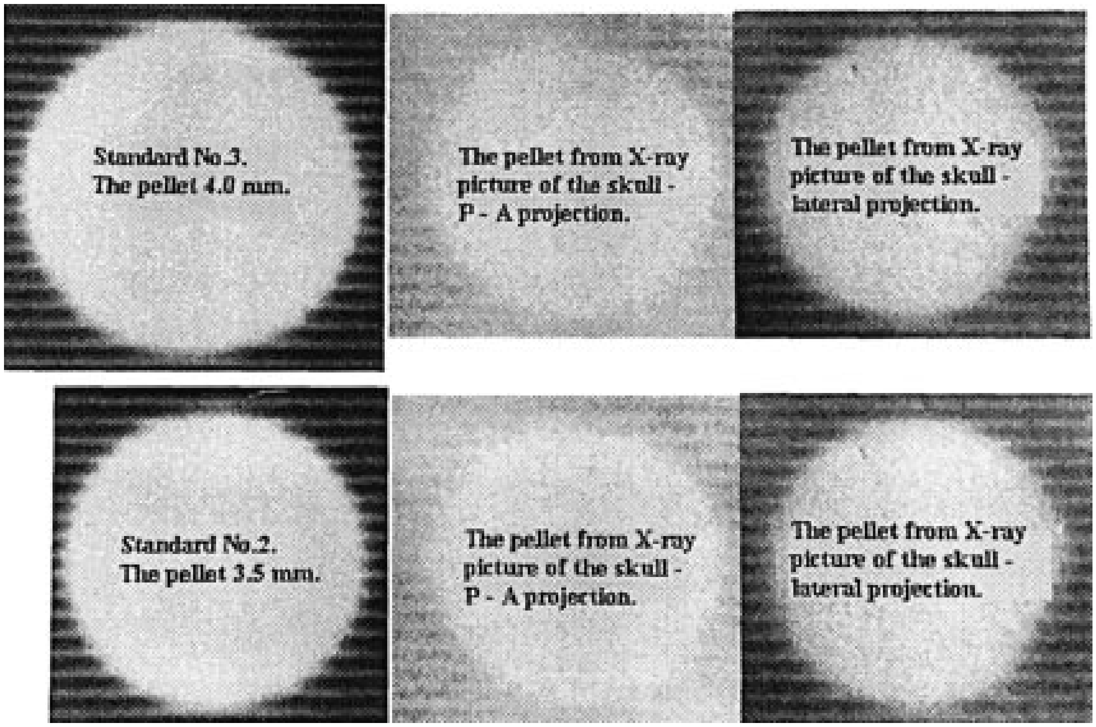

FIG. 5—*Comparison of dimensions of pellets from X-ray pictures.*

thick (or thinner) was necessary for our purposes. This examination requires a higher radiation dose to retain image quality. Further, the spatial resolution of CT is inferior to skiagraphy (7). Next, even with CT, the size of the real object and its CT image is not 1:1 and must be related to the measuring device. The possible artefacts caused by a metallic foreign body must be considered also. These were reasons why we used conventional X-ray.

Establishing the exact size of the foreign body may cause problems, especially when very small differences in size have to be determined. Simple measurement is not sufficient because the dimensions may change due to different results. The deformation of the object due to an impact must be considered. The ''circularity'' parameter is important from this point of view, and probable pellet deformation was tested using this parameter. The pellet was not deformed—or only inappreciably—as expressed by the values of this parameter. In the case of a substantially changed value in a deformed pellet it should be necessary to find which morphometric parameter represents best the ''pellet dimension.'' Evaluation of the circularity is very easy in the LUCIA image processor and we can perform it simultaneously with the evaluation of other parameters.

Other very important factors are conditions under which the X-ray is taken. We found that the parameter values obtained by direct image analysis of standard calibrating pellets (Table 2) differ substantially from the parameters values obtained using image analysis of the roentgenogram of the pellet in the orbit and the roentgenogram of the standard calibrating pellets (Table 3). The values of the parameters obtained by direct image analysis of the standard calibrating pellets correlate very well to their actual size. The values of the parameters obtained by the image analysis of the roentgenogram of the pellet in the orbit and the roentgenogram of the standard calibrating pellets were higher and did not correspond to the actual size of the pellets. However, it is evident that the values of the parameters of the pellet from the orbit correspond best to the values of the calibrating pellets measuring 3.5 mm. This fact documents that the object-to-film distance was correctly set up. These assessed morphometric parameters were not corrected by a magnification factor because only objects on roentgenograms were compared and their magnification was the same. After mathematical correction of values in Table 3, using a magnification factor (from Table 1), we establish the real diameter. For example: the parameter ''area'' is calculated:

$$\text{area} = \pi d^2/4$$

Next the parameter ''EqDiameter'' is calculated in the image processor LUCIA (4) according to the equation

$$\text{EqDiameter} = \sqrt{\frac{4 \times \text{area}}{\pi}}$$

so we derive the real diameter D_r from

$$D_r = \frac{\sqrt{4 \times \dfrac{\text{area}}{\pi}}}{\text{Magnification factor}} = \frac{\sqrt{4 \times \dfrac{9.34}{3.14}}}{1.146} = 3.009$$

This value corresponds very well to the value of the parameter ''EqDiameter'' for the 3.00-mm-size pellet determined by the direct video image analysis of standard calibrating pellets (Table 2). In this way we also can recalculate other values. Smaller values of pellets on the PA projection were found. We account for this fact as being due to the distortion and unsharpness of the object's picture caused by material and geometrical influences during the X-ray examination. The thresholding of the object during the image analysis may also play a part. However, this value, when corrected by the magnification factor, is still within the range of acceptable error and does not fall to the values for the smallest pellets (3 ± 0.125 mm). This error can be accepted because we proved that no pellet exceeded the range of its size group.

Conclusion

Different values of morphometric parameters from image analysis were found when the direct video image and roentgenogram of the pellets were evaluated. In spite of these differences, roentgenogram values of the pellet in the orbit and values for the standard calibrating picture of the 3.5 mm pellet were consistent; thus we were able to determine the size of the pellet.

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Additional information and reprint requests:
Alexander Pilin, M.D., Ph.D.
Institute of Forensic Medicine
University Hospital in Prague
Studničkova 4, 128 00 Prague
Czech Republic