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ORIGINAL ARTICLE

Analysis of experimental cranial skin wounding from screwdriver trauma

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Abstract As part of a more extensive investigation of skin wounding mechanisms, we studied wounds created by five common screwdrivers (straight, star, square or Robertson, Posidriv and Phillips) on the shaven foreheads of 12 freshly slaughtered pigs. We fixed the different screwdriver heads to a 5-kg metal cylinder which was directed vertically onto each pig head by a droptube of 700 mm length. We examined skin lesions by photography and also by scanning electron microscopy (SEM). Our evaluation of differences in wound shape and size was based on geometric morphometric methods. Our results show that there are obvious morphological differences between the straight head and the other types. The straight-headed screwdriver penetrates the skin by a mode II crack which results in a compressed skin plug with bundles of collagen fibres forming skin tabs within the actual wound. The sharper-tipped screwdrivers wedge open the skin (mode I), with a clearly defined edge with no skin plugs. Geometric morphometric analysis indicates that shapes of skin wounds created by the five screwdriver types could be classified into three different groups. The straight head results in the most differentiated wound profile, with the Robertson or square and some specimens of star, and also the Posidriv and Phillips giving similar wound outlines. SEM evaluation of wounds created by a new and worn straight-head screwdrivers shows that the outline of the worn screwdriver head is reflected in the shape of the wound it created.

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Introduction

Forensically, few cases of cranial skin wounding by screwdrivers have been reported, and little or no work on documenting the patterning and range of morphological features that characterise such wounds has been undertaken. Yet, screwdriver stab wounds are often described in the surgical and traumatological literature [1–6], which has prompted the call by Trutton et al. [7] for an increased awareness of such injuries to the skin. Moreover, a number of recent reports [8–10] have highlighted the importance of a careful analysis of dermal stab wounds in forensic investigations.

While some studies have investigated the morphological characteristics and individualization of sharp-force trauma to bone and cartilage [11–14], to the best of our knowledge, there has been only one such investigation on the overlying skin [15]. Typically, sharp-force trauma is described as stabbing, slashing or chopping wounds inflicted by a sharp object such as a knife or a screwdriver [10]. Often, such trauma is not readily identifiable with the naked eye and has to be magnified through photographic processes. Rawson et al. [8] have underlined an inherent limitation in the use of photographs, in that they fail to capture details of the third dimension or depth of a wound, and have advocated the use of scanning electron microscopy (SEM) in such cases. The question arises, can skin wounds inflicted by different screwdriver types be characterised? If they can, is it possible to ascribe individual characteristics such as wear patterns to a given screwdriver wound?

The aims of the present study were, firstly, to examine the morphology of experimentally produced wounds on the cranial skin of pigs and, secondly, to see whether different types of screwdriver may be recognised by the pattern of skin trauma they inflict. Finally, we also investigated possible differences in wound morphology brought about by wear and tear of different screwdriver heads.

Materials and methods

We evaluated sharp-force trauma to the skin on the shaven foreheads of 12 adult female pigs, *Sus scrofus*, that were freshly slaughtered and not refrigerated or chemically preserved. Because ethical restrictions in New Zealand and Australia preclude the use of human bodies for forensic experimentation, pigs have been used as reliable alternatives [16, 17]. To simulate the trauma, five different screwdriver heads (straight, Phillips, Posidriv, square or Robertson and star-shaped) were fixed onto a metal cylinder of 5 kg weight (Fig. 1). Each screwdriver head was firmly embedded into a milled channel and fixed by tightening a worm screw. The cylinder was then directed down a vertical droptube of 700 mm length, onto each pig's forehead. The entire process was repeated using exactly the same methodology, but with five worn screwdriver heads of the same types.

Morphological analysis

Lesions produced were photographed and examined in situ, then excised for SEM. After sputter coating with gold–palladium, excised lesions were evaluated using a JeolJ SM5410LV scanning electron microscope (JEOL, Tokyo, Japan) at ×15 and ×75 magnification. The SEM analysis included features of the edges and walls of each lesion.

Geometric morphometric analysis

To analyse size and shape variation within and among the different screwdriver types (i.e. straight, Phillips and Posidriv, square and star-shaped screwdriver heads), we used two landmarks and ten semi-landmarks (points allowed to slide along curves to minimise bending deformation) located on each wound outline to describe each lesion. Landmarks 1 and 7 corresponded to the extreme points of the longest axis. Because there may be few geometrically homologous anatomical features on a wound outline, the use of landmarks is not sufficient to capture aspects of the morphology which are relevant to this. Hence, we employed ten semi-landmarks located between the two landmarks. Figure 2 shows the points digitized in the wound outline obtained with a Phillips screwdriver. Both landmarks and semi-landmarks were digitized using tpsDIG 1.44 software [18].

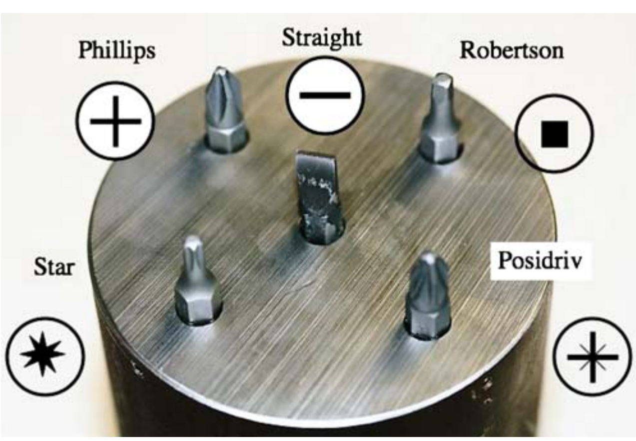

Fig. 1 Five different screwdriver heads (straight, Phillips, Posidriv, square or Robertson and a star-shaped) fixed onto a metal cylinder of 5 kg weight. Each screwdriver head is firmly embedded into a milled channel and fixed by tightening a worm screw

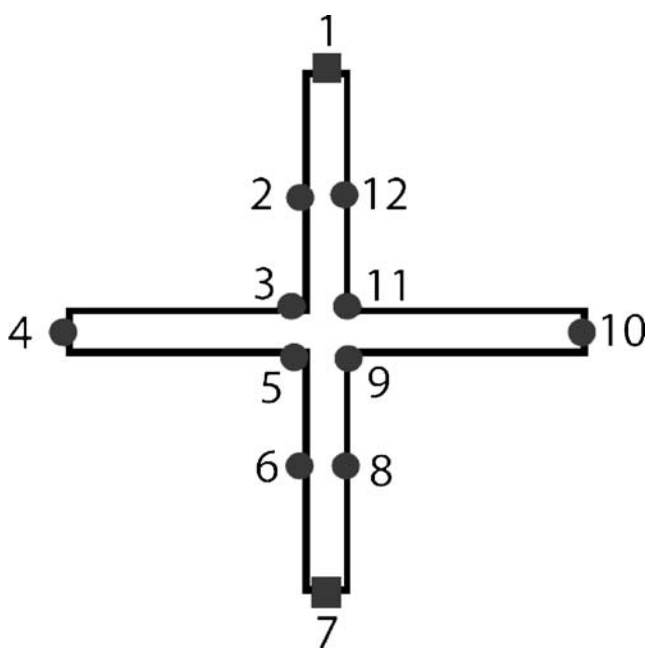

Fig. 2 Allocated landmarks (*square*) and semi-landmarks (*circle*) on the wound outlines obtained with a Phillips screwdriver. *RW* Relative warp, *PC* principal component

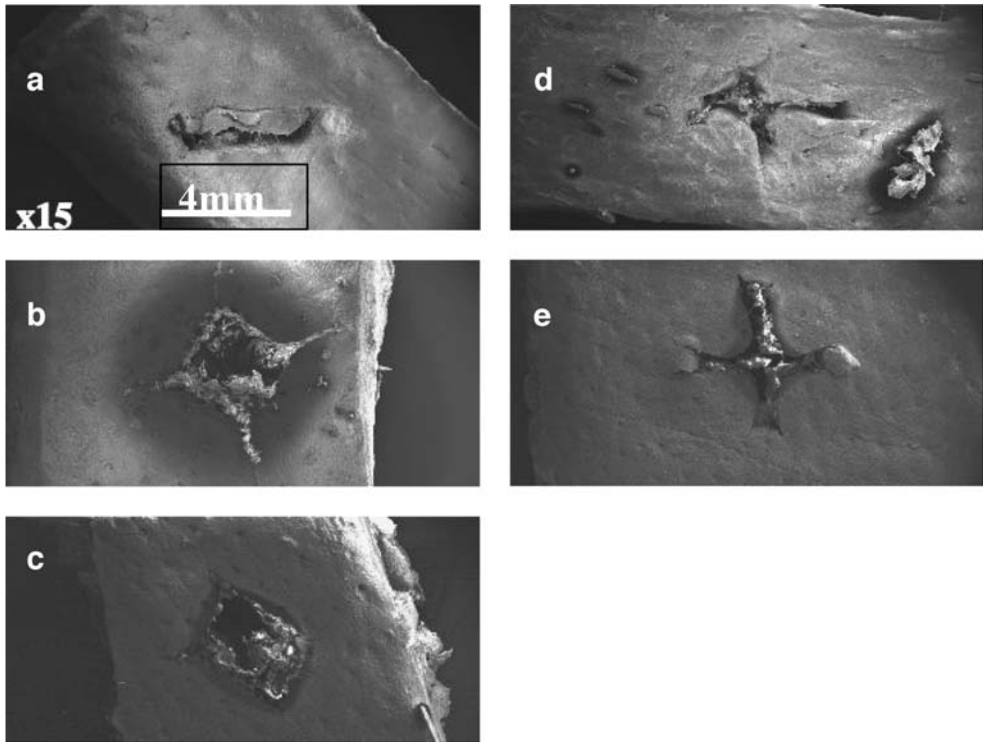

Fig. 3 Photographs of excised wounds created by the five screwdriver heads on the forehead skin of a domestic pig. SEM views of skin wounds created by straight head (**a**), Robertson (**b**), star (**c**), Phillips (**d**) and Posidriv (**e**). Magnification, ×15

In geometric morphometric analyses, shape is defined as the information remaining in a configuration of coordinates of points after the differences due to location, scale and orientation are removed [19]. We employed the generalised Procrustes analysis [20, 21] to remove the effects of these variables. In addition, semi-landmarks were aligned by means of minimum Procrustes distance criteria [22, 23]. This operation slides the semi-landmarks along the outline curve until they match the positions of corresponding points along the outline of a reference specimen as well as possible [24]. This is done because the variation along tangent directions is not informative and only the coordinate normal to the outline carries information about differences between specimens [22–25]. In this study, SemiLand6 software [26] was used to align the semi-landmarks along their respective curves, sliding them along so as to minimise the Procrustes distance between the subject and the reference [27].

To analyse shape variation of wounds within and among screwdriver types, we performed a principal components analysis (PCA), known as relative warp analysis. This is

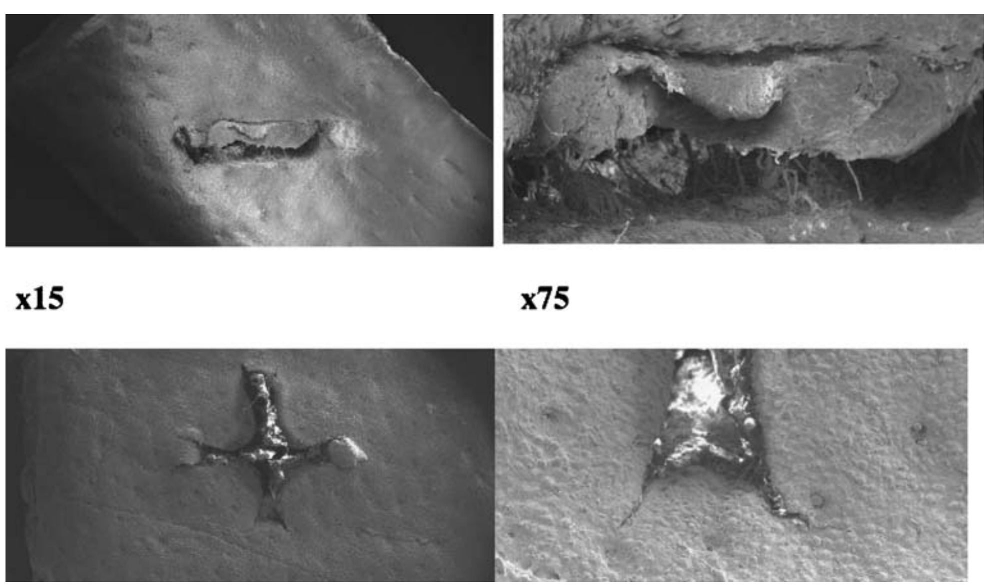

Fig. 4 Low-power (×15) and higher-power (×75) SEM views of the wounds created by a straight-head (*top*) and a Posidriv (*bottom*) screwdriver. Notice the retained skin plug in the top view and angular dermal tears in the bottom view

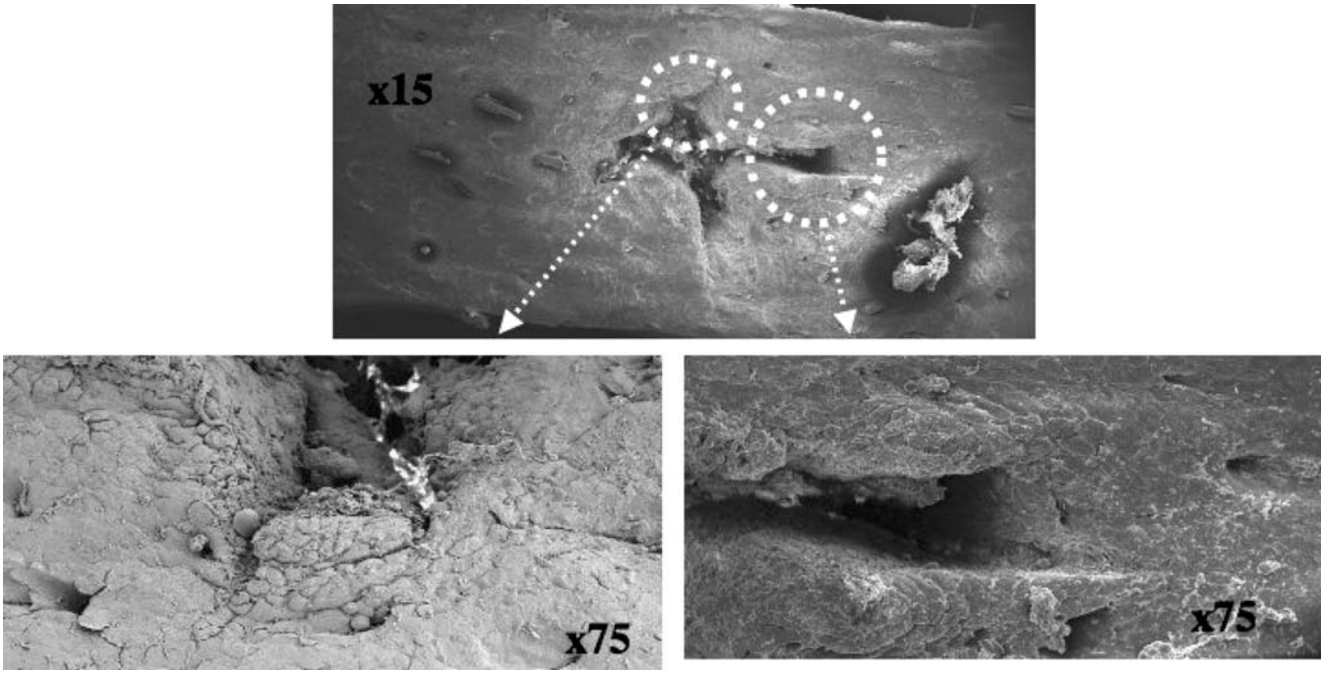

Fig. 5 Low- (×15) and higher-power (×75) views of the wound created by a Phillips screwdriver. Note the absence of a skin plug and the presence of small dermal tears at the angles of the wound

based on the partial warp scores plus the uniform components, derived using thin-plate spline decomposition of the bending energy matrix from the partial Procrustes aligned landmark and semi-landmark coordinates [28, 29]. The partial warp scores are components along the orthogonal eigenvectors of the bending energy matrix and describe non-affine patterns of shape difference [19, 30], whereas the uniform components describe affine shape differences [31, 32]. An advantage of the thin-plate spline method is that it allows for use in the intuitive deformation

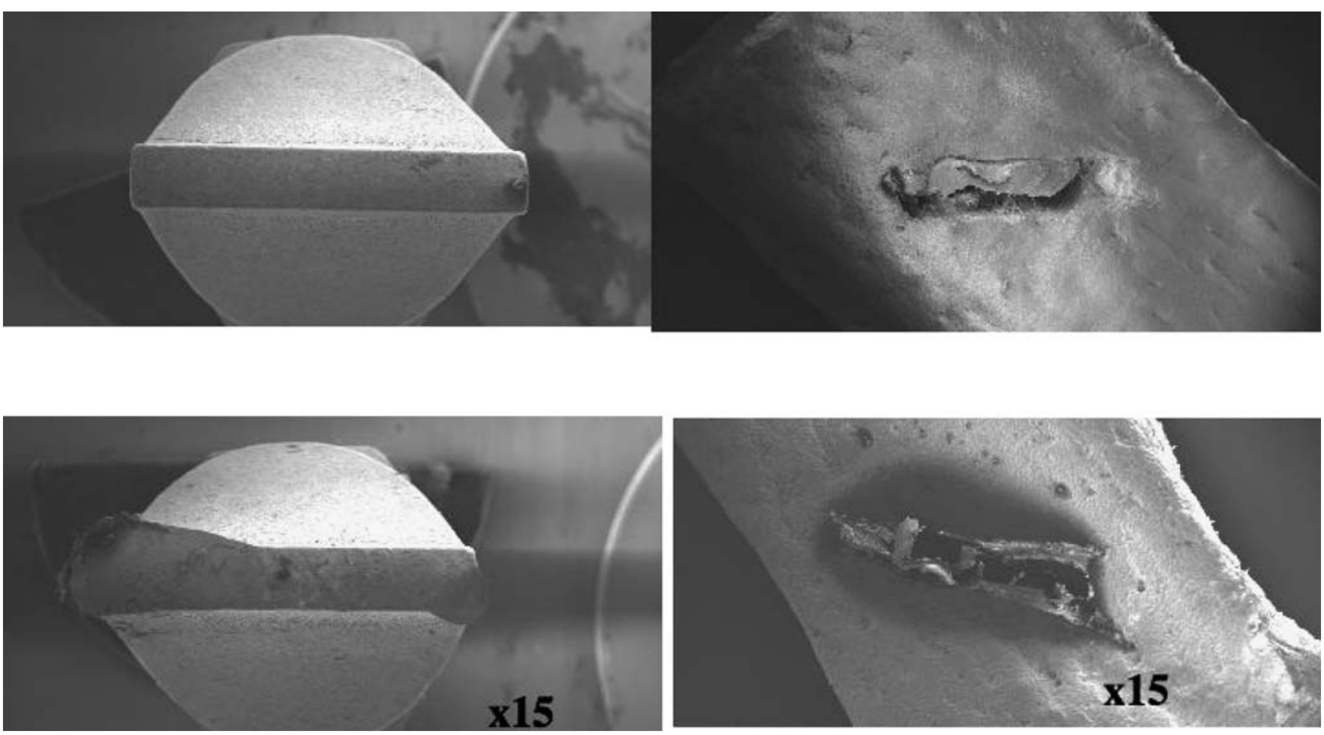

Fig. 6 SEM views of the heads of a new (*top*) and worn (*bottom*) screwdriver head, together with the wounds they created

grid diagrams to depict shape changes. Relative warp analysis was performed using tpsRelw 1.44 software [18].

Morphological variation in shape within each sample was evaluated using Foote's [33] disparity measurement. This is defined as morphological disparity $D = \left(d_i^2\right) / (n-1)$ where d_i represents the distance of the specimens to the group centroid. Disparity was measured using DisparityBox6 software [26], which uses the partial Procrustes distance as d_i measure. A bootstrap procedure (n=900) was used to establish the significance between disparity measurements.

Discriminant function analysis was then performed on the relative warps that accounted for 90% of the explained variance. A jackknife procedure was employed to assess how well the assignment was using the discriminant function.

Finally, to represent the differences in wound form (size plus shape) among individual screwdriver types, a PCA was performed on z z-standardised partial warps, uniform component scores and centroid size (the square root of the summed square distance of all landmarks from the centroid). Then, discriminant function analysis was carried out on the principal components that account for 90% of the explained variance. The variation in size within each screwdriver type was measured by the variance of centroid size, whereas the variation in form was estimated as the mean of the variances of z-standardised values of partial warps, uniform component scores and centroid.

Results

Wound morphology

Typical skin wounds resulting from the impact of the five different screwdrivers are presented in Fig. 3. There are obvious morphological differences between the straight head and the other types. While wounds generated by the Posidriv and star heads are noticeably different, dissimilarities between square, Phillips and Posidriv heads are not as obvious. SEM views of wounds inflicted by all five screwdriver heads are shown in Fig. 4. Again, the straight head (a) stands out as the most characteristic, with Robertson and star heads (b and c) being very similar.

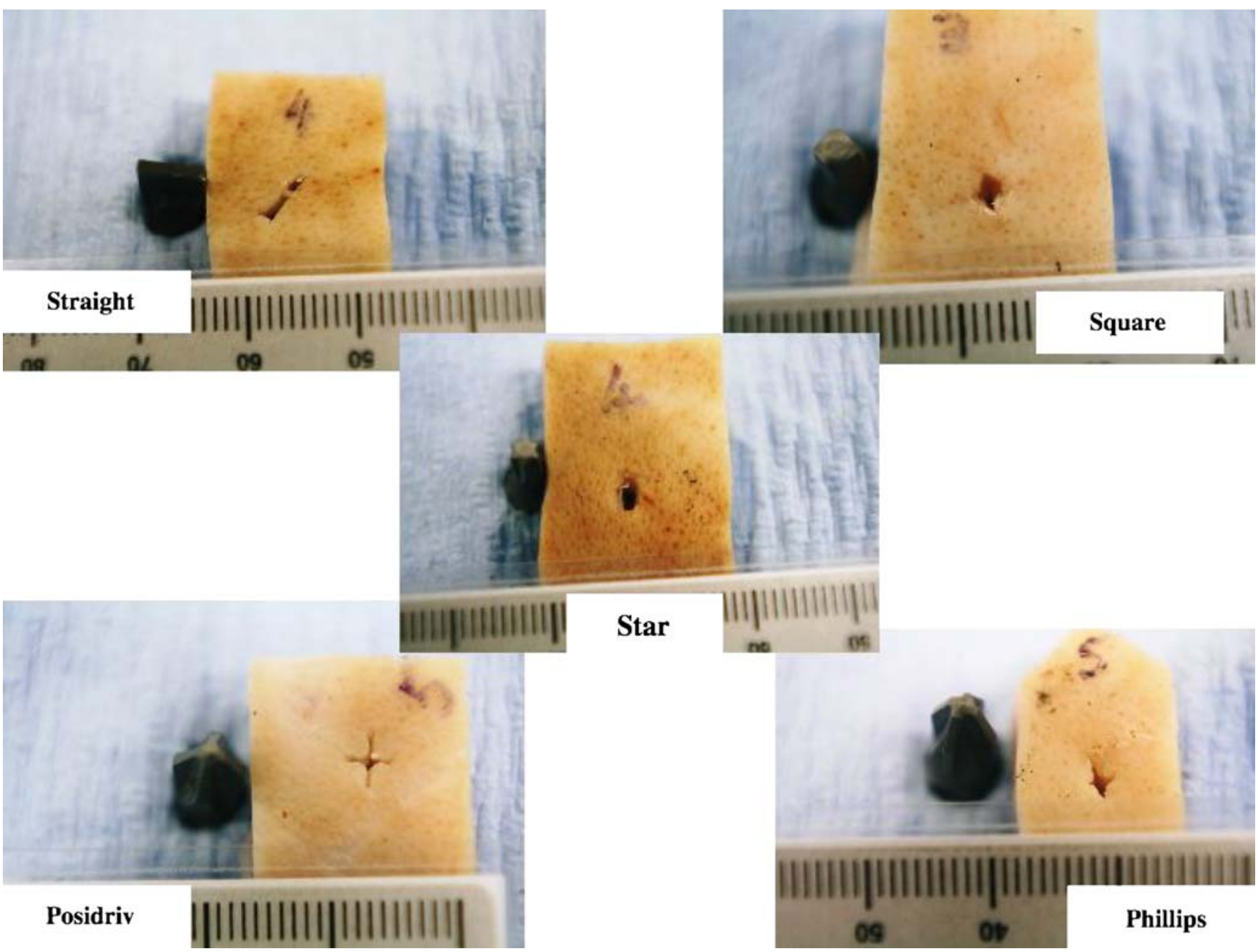

Fig. 7 Photographs of excised wounds created by the five screwdriver heads on the forehead skin of a domestic pig

The Robertson or square head wounds may be distinguished from the star, however, by extension tears at the angles of the square wound (b). The Phillips (d) and Posidriv (e) wounds appear to be indistinguishable at this magnification. At higher magnification, an intact but deformed skin plug with bundles of collagen fibres forming skin tabs is visible in the straight-head screwdriver wound (Fig. 4, top). In contrast, the high-power view of one of the arms of the Posidriv wound shows the absence of a plug of skin tissue, with two characteristic tears at the angles of the wound (Fig. 5, bottom). These are absent in the straight-head screwdriver wound. Examination of high-power views of the wound created by the Phillips head similarly shows an absence of a skin plug and smaller angular tears in the dermis (Fig. 6). SEM views of the wounds created by a new (top) and worn (bottom) straight-head screwdriver are given in Fig. 7. It is clear that the outline of the worn screwdriver head is reflected in the shape of the wound it created.

Inter- and intra-class shape differences

Relative warp analysis indicates that the shapes of skin wounds created by the five screwdriver types could be classified into three different groups. The straight head results in the most differentiated wound profile (Fig. 8, bottom left), with the Robertson or square and some specimens of star (Fig. 8, bottom right), and also the Posidriv and Phillips (Fig. 8, top central) giving similar wound outlines. Foote disparity measurements indicate that wound profiles of straight type form the least variable group (Table 1) and differ significantly from the other four types. Conversely, the shapes resulting from Posidriv type are the most variable, but these differences were not statistically significant (Table 1). Discriminant function analysis was performed on the first five relative warps that

Table 1 Distance-based (Foote) disparity and the 95% confidence interval for the disparity over the 900 bootstrap iterations

	Foote disparity	Confidence interval
Phillips	0.033	0.014 to 0.034
Posidriv	0.063	0.024 to 0.078
Square	0.021	0.007 to 0.025
Star	0.041	0.019 to 0.049
Straight	0.004	0.001 to 0.004

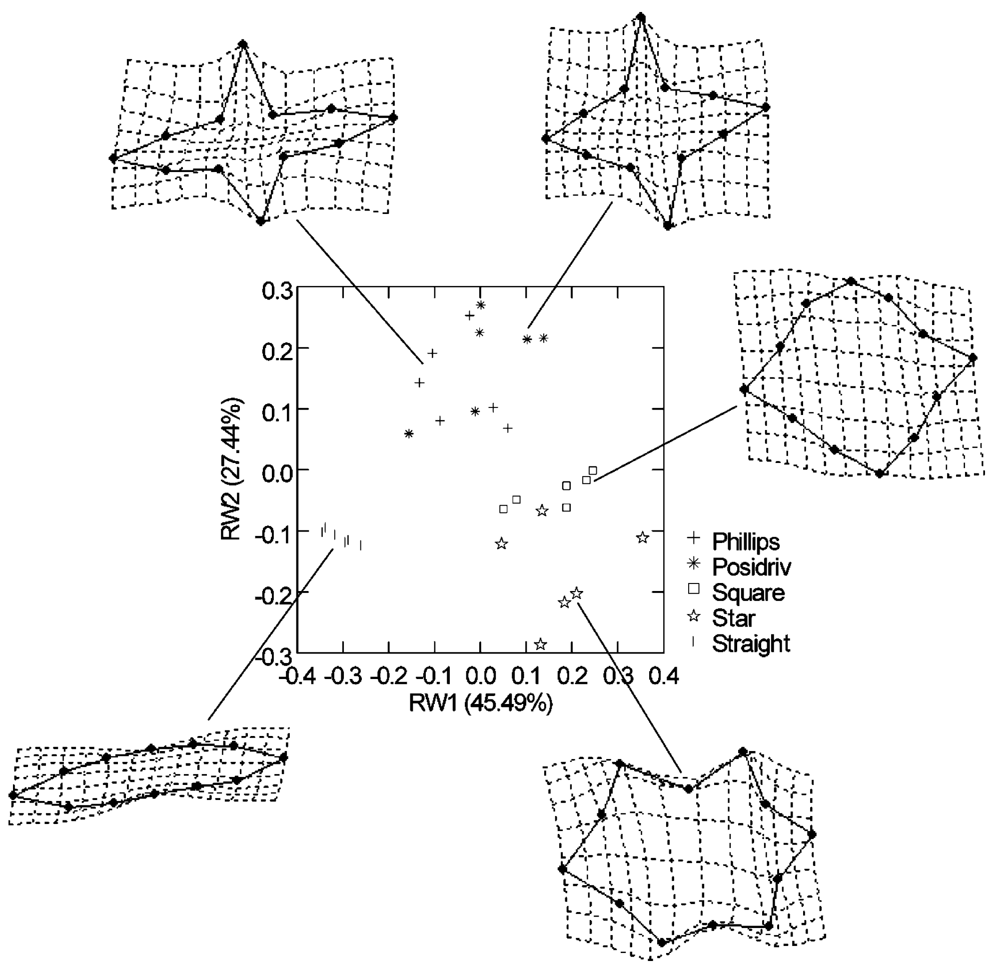

Fig. 8 Relative warp analysis of the wound shapes generated by the five screwdriver heads. These fall into three broad types—wounds created by the straight head (*bottom left hand*), those created by the star and Robertson heads (*top left and right*) and those created by the Posidriv and Phillips heads (*bottom right*)

Table 2 Jackknifed classification matrix obtained from the discriminant function analysis performed on the first five relative warps

	Phillips	Posidriv	Square	Star	Straight	%Correct
Phillips	6	0	0	0	0	100
Posidriv	3	3	0	0	0	50
Square	0	0	5	2	0	71
Star	0	0	1	4	0	80
Straight	0	0	0	0	6	100
Total	9	3	6	6	6	80

Cases are in rows and categories classified into columns.

account for the 90.34% of the variance explained. When a jackknife procedure was employed, 80% of the wound forms are correctly assigned to their screwdriver types by the discriminant function (Table 2). The lowest values were obtained for Posidriv and square types (50 and 71%, respectively).

Inter- and intra-class form differences

The box plot for screwdriver types shows great dispersion of centroid size within each type, the square type being the least variable (Fig. 9). PCA performed on shape and size variables (partial warps, uniform component scores and centroid size) indicates that skin wounds created by the straight and square heads result in the most closely grouped wound profiles (Fig. 10, centre). The Posidriv and Phillips form a group and the star another group with greater dispersion (Fig. 10, left). Regarding to the variance in size and form variables, square-shaped wounds display the lowest value of variance in centroid size, while star-shaped wounds display the highest value (Table 3). Conversely, the lowest value for shape was found in straight type, whereas the highest values were found in Posidriv and star types (Table 3). Discriminant function analysis was performed on the first ten principal components that account for 92.78% of the variance explained. After jackknifing, only 73% of the wound shapes were correctly assigned to their screwdriver types (Table 4). The lowest values were obtained for Posidriv and square types (50%).

Discussion

Our paper focuses on three inter-related issues. Firstly, we examined the morphology of experimentally produced wounds on the cranial skin of the pig, and secondly, we investigated whether different types of screwdriver may be recognised by the pattern of skin trauma they inflict. Finally, we investigated the possible differences in wound morphology brought about by wear and tear of different screwdriver heads.

Skin is a biologically composite material that consists primarily of water and a fibrous network. The latter has been described as an alignable collagen network intermeshed with an elastin network in a ground substance of proteoglycans

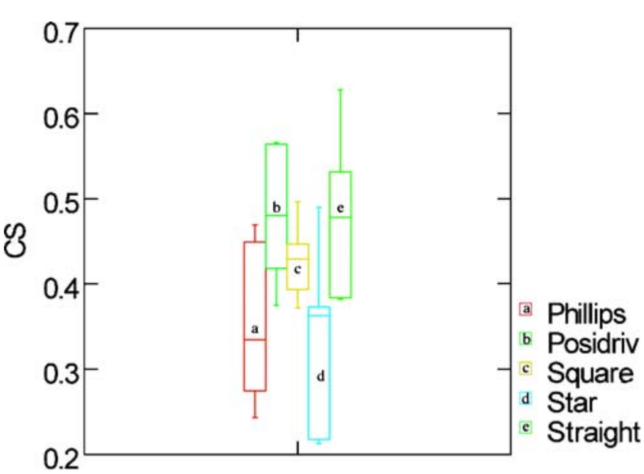

Fig. 9 Box plot of centroid size for each screwdriver type

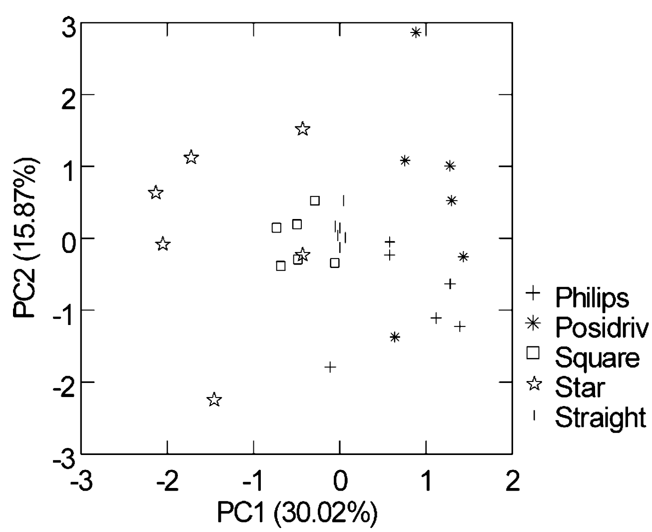

Fig. 10 PCA performed on partial warps plus centroid size generated by the five screwdriver heads

Table 3 Variance of centroid size and form

	Phillips	Posidriv	Square	Star	Straight
Centroid size	0.860	0.600	0.189	1.080	0.854
Form	0.706	1.206	0.357	1.080	0.118

[34]. Human skin behaves as a non-homogenous, anisotropic, non-linear viscoelastic material subject to prestress. Because one of its primary functions is to protect the internal organs from mechanical trauma, skin is viscoelastic with a two-phase response to mechanical force applied to it. This involves, firstly, a viscous component associated with the dissipation of energy and, secondly, an elastic response associated with energy storage [35]. Shergold and Fleck [36] have proposed a simple model of blunt force trauma that can be used to reveal the basic mechanisms that control fracture mechanics of human skin and a simulant (silicone rubber) by developing a micromechanical model for deep penetration of blunt- and sharp-tipped cylindrical punches. Their model suggests that the mechanism of penetration depends upon the geometry of the punch tip. While a blunt tip penetrates by the growth of a ring (mode II or tearing) crack, a sharp tip wedges open a planar (mode I-opening) crack. They [35] predict that a blunt punch penetrates by an unstable crack advance and results in a compressed column of material at the bottom of the cylindrical cavity thus created. In contrast, the sharp punch tunnels into the tissue at a penetration pressure several times lower than that of a blunt punch. This implies that blunt-force injury requires more energy than sharp-force injury, and that the former will result in larger, more irregular wounding. Our study clearly supports Shergold and Fleck's predictions. The straight-headed screwdriver penetrated the skin by a mode II crack, which resulted in a compressed skin plug with bundles of collagen fibres forming skin tabs within the actual wound (Fig. 5, top). This is consistent with Brinkmann and Kleiber's [15] earlier study on the skin wound patterns of different sizes of straight screwdrivers. The sharper-tipped screwdrivers wedge open the skin (mode I), which results in a clearly defined edge with no skin plugs (Fig. 5, bottom).

The second question we address is can an examination of the skin wound identify the characteristics of the injury tool itself? In other words, can different types of screwdriver be recognised by the pattern of skin trauma they inflict? Both Rawson et al. [8] and Sitiene et al. [10] emphasise the importance of the assessment of wound characteristics in the identification of the wounding instrument. Our study shows clearly that wounds inflicted by different types of screwdriver may be grouped into three categories. Firstly, the straight-head screwdriver produces a wound that is characteristic and clearly identifiable from all the others (Fig. 8; Table 1). The second grouping consists of wounds inflicted by square- (Robertson) and star-head screwdrivers, and the third group consists of the Posidriv and Phillips screwdrivers (Fig. 8). Wound outlines created by the straight-headed and square screwdriver are the least variable with a 100% correct assignment in discriminant functional analysis (Tables 3 and 4). In contrast, the group of star, Posidriv and Phillips screwdrivers shows wound outlines that are highly variable, with the star head being correctly classified in only 50% of cases. These data present the first qualitative analysis of wounding patterns of different screwdriver heads and clearly show that straight screwdrivers deliver the most distinctive and identifiable wounds. While skin wounds created by square-head (Robertson) screwdrivers are also distinct, those delivered by star, Phillips and Posidriv cannot be reliably separated.

The final question we ask is how does wear of the injuring screwdriver affect its wounding pattern? The only instrument that showed a clear difference between wounds created by new and old is the straight-headed screwdriver (Fig. 7), and the difference is only clearly visible at the SEM level. Thus, while we share the optimism of Rawson et al. [8] about the usefulness of SEM comparisons of wounds and the instruments that inflicted them, our results suggest that caution is warranted in interpreting the morphology of screwdriver wounds to the skin.

Table 4 Jackknifed classification matrix obtained from the discriminant function analysis performed on the first ten principal components

	Phillips	Posidriv	Square	Star	Straight	%Correct
Phillips	4	0	2	0	0	67
Posidriv	3	3	0	0	0	50
Square	0	0	6	0	0	100
Star	1	0	2	3	0	50
Straight	0	0	0	0	6	100
Total	8	3	10	3	6	73

Cases are in rows and categories classified into columns.

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