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Detection of foreign particles in traumatized skin

T. Bajanowski[1], **K.-B. Hüttenbrink**[2], **and B. Brinkmann**[1]

[1]Institut für Rechtsmedizin, Universität Münster, Von-Esmarch-Strasse 86, W-4400 Münster, Federal Republic of Germany
[2]Hals-Nasen-Ohrenklinik, Universität Münster, Kardinal-von-Galen-Ring 10, W-4400 Münster, Federal Republic of Germany

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Summary. The aims of the medico-legal investigation of wounds are a description of the wound morphology, the characterization of the force used and finally identification of the weapon. The demonstration of foreign particles, such as wood particles, paint fragments, synthetic materials, sand or gravel particles, powder residues and rust particles, in the depth of a wound or in the surrounding area can be of great value. In the present series of experiments the suitability of imaging methods (low energy X-ray imaging, direct X-ray magnification, nuclear magnetic resonance) for the detection of relevant foreign particles has been investigated.

Key words: Skin wounds – Detection of foreign particles – X-ray techniques – Nuclear magnetic resonance (NMR)

Zusammenfassung. Ziel der rechtsmedizinischen Untersuchung von Wunden ist neben der Beschreibung der Wundmorphologie die Charakterisierung der einwirkenden Gewalt einschließlich der Bestimmung des verursachenden Werkzeugs. Hierbei kann der Nachweis bestimmter Fremdkörper (Holzpartikel, Lacksplitter, Kunststoffteilchen, Leder, Glas, Sand- oder Kiespartikel, Pulverschmauch, Rostpartikel) in der Tiefe einer Verletzung oder in deren Umgebung wertvolle Hinweise geben. In der vorliegenden experimentellen Untersuchung wurde die Frage erörtert, wie weit bestimmte bildgebende Verfahren (Weichstrahlröntgenuntersuchung, direkte Röntgenvergrößerung, Kernspintomographie) zur Detektion entsprechender Fremdkörper in Verletzungen geeignet sind.

Schlüsselwörter: Hautverletzungen – Fremdkörpernachweis – Röntgentechnik – Kernspintomographie

Introduction

The medico-legal investigation of wounds concentrates mainly on two questions: (1) Type and mode of force (direction, energy, blunt/sharp force), (2) characterization of the implement. Whereas the first complex is already textbook knowledge (Ponsold 1967; Mueller 1975; Prokop and Göhler 1976; Forster 1986), the second complex has been relatively little researched. This concerns both information about the type of instrument (e.g. Janssen 1963 -hammer-; Brinkmann and Kleiber 1978 -screwdriver-; Bajanowski et al. 1991 -glass-) and also substances and particles which are transferred by physical contact between the instrument and tissue. – This group have previously reported on the use of a new high resolution X-ray technique for the demonstration of minute particles (Hüttenbrink et al. 1989; Paldauf et al. 1989; Bajanowski et al. 1991). The technique is able to detect microscopically small particles where other methods fail. In this study the scope of this technique has been experimentally investigated. Simultaneously a promising application of another visualization method, nuclear magnetic resonance (NMR) will be described.

Offprint requests to: B. Brinkmann

Materials and methods

1. *Experimentally impregnated skin preparations*

Incisions were made in post mortem skin preparations using a scalpel and particles of various materials of defined size were inserted in the wound. Details of the foreign bodies were as follows:

(a) Synthetic particles from headlight and indicator housing of a car. Particle-size: 1×1 mm, 1.5×1 mm, 3×1 mm;
(b) soft wood (fragment of a matchstick): Particle size: 1.5×1.5 mm, 5×1.5 mm, 7×1.5 mm, 10×1.5 mm;
(c) hard wood (beech tree fragments). Particle size: 4×1.5 mm, 6×1.5 mm, 9×1.5 mm;
(d) various car paints (acrylic base). Particle size: 10×1.5 mm, 20×2.5 mm, 30×2.5 mm;
(e) safety glass from the windshield of a car. Particle size: 1.5×2 mm, 2×2 mm, 3×2 mm, 5×2 mm;
(f) leather. Particle size:
2×2 mm, 3×2 mm, 5×2 mm, 10×2 mm;
(g) synthetic leather. Particle size: 3×2 mm, 4×2 mm, 7×2 mm.

To enable an approximate size comparison two steel particles (diameter 1 mm) were included in every preparation.

2. *Injuries caused by various types of force*

2.1. Blunt force. Skin preparations were traumatized using various instruments. In each case the instrument to be tested was dropped from a height of 80 cm onto the horizontally positioned skin preparation to produce an injury. The following implements were employed:

(a) Rusty iron rod (diameter 13 mm, length 1 m);
(b) concrete paving stone, compressed form;
(c) red roofing tile with and without glazing on the surface;
(d) limestone, poured form;
(e) red brick.

2.2. Experimentally induced gunshot wounds. Gunshot wounds were made in skin preparations using a captive-bolt humane killer and a revolver, calibre .44. Shots with the revolver were made at close-range and relatively close distances (0–30 cm).

3. Methods

The skin preparations which had been experimentally impregnated with various materials were all investigated using low energy X-ray imaging. When the particles showed X-ray contrast additional direct X-ray magnification was carried out.

The preparations for the range of investigations using blunt force (2.1.a–e) were also investigated using low energy X-ray imaging. The preparations 2.1.a (iron rod), 2.1.b (concrete paving stone) and 2.1.e were also routinely investigated using direct X-ray magnification.

The experimentally prepared shooting injuries (2.2.) were investigated with low energy X-ray imaging, direct X-ray magnification as well as nuclear magnetic resonance. Furthermore, investigations of the blunt force injuries caused by an iron rod were carried out using electron magnetic resonance (2.1.a).

Results

1. Experimentally impregnated skin preparations

The low energy X-ray imaging of various foreign particles showed that synthetic particles from the light and indicator housing of cars did not normally absorb X-rays. As expected soft wood and hard wood fragments also showed no contrast by X-ray analysis. Therefore documentation of these investigations was dispensed with.

Acrylic paint particles however could clearly be demonstrated using low energy X-ray imaging as well as by the micro-radiography method. Under the micro-focus X-ray tube the 3-dimensional structure of the very flat paint fragments with tooth-like projections of the broken edges could easily be recognized by turning the preparation (Figs. 1, 2). The demonstration of glass particles was possible using the soft beam technique and also by X-ray magnification. Minimum particle sizes of approximately 300 μm could be successfully demonstrated using the low energy imaging technique. Glass components (minimum size approximately 20 μm) could be detected

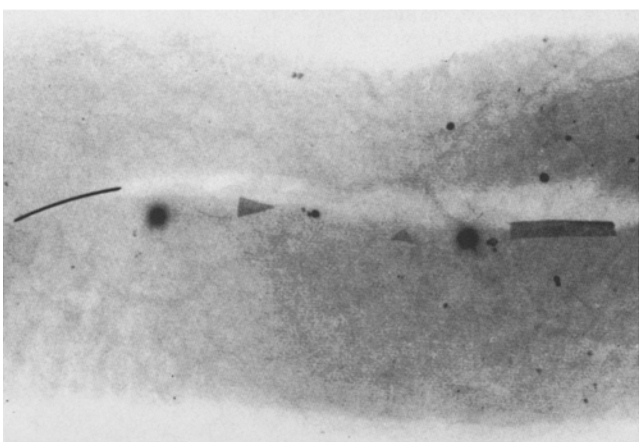

Fig. 1. Particles of acrylic paint (low energy X-ray imaging). For comparative purposes 2 steel balls (diameter 1 mm) are included

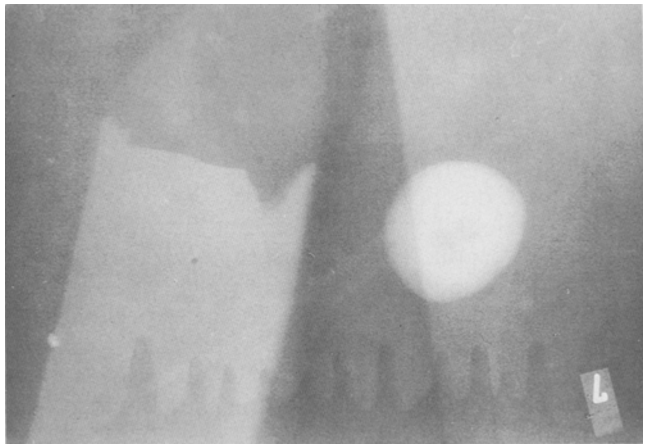

Fig. 2. Paint particle by 30 × direct X-ray magnification. Typical angular and tooth-like structure of the edge. Steelball diameter 1 mm

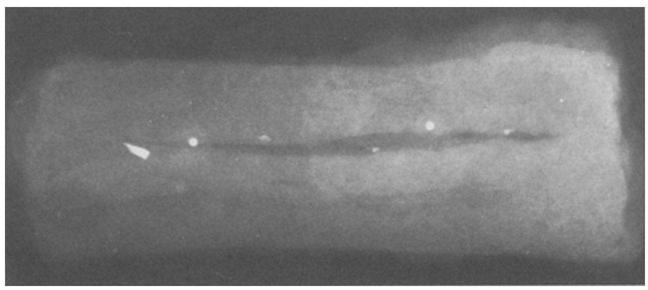

Fig. 3. Sliver of safety glass (low energy X-ray imaging)

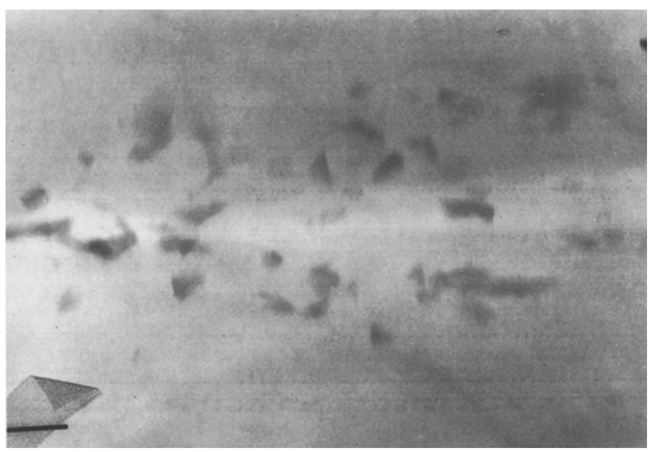

Fig. 4. Glass dust in the surroundings of a laceration. Direct X-ray magnification (40 ×)

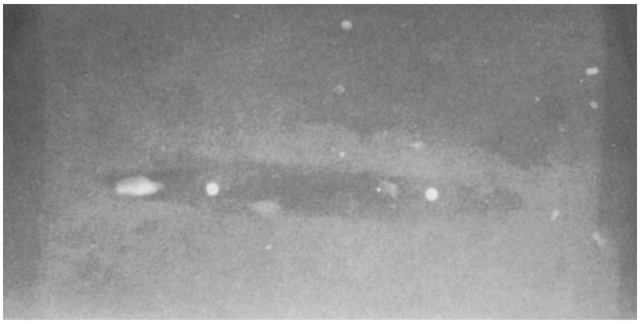

Fig. 5. Synthetic leather in a skin wound. Varying intensity of contrast using low energy imaging

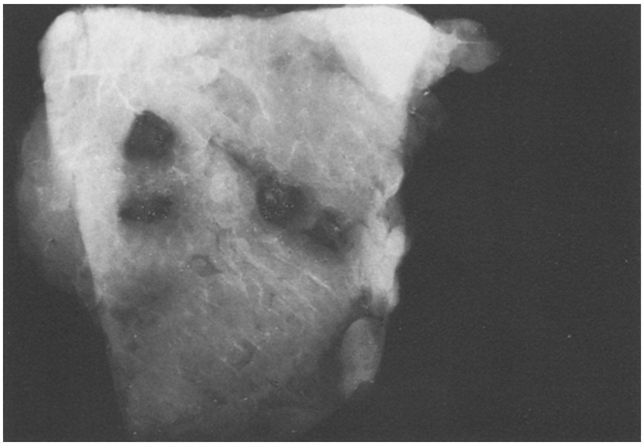

Fig. 6. Skin traumatized by a rusty iron rod with clearly visible metal and rust particles (low energy imaging)

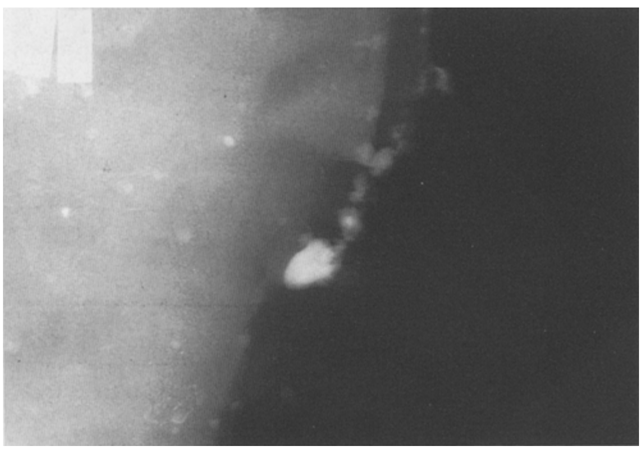

Fig. 7. Tangential image of traumatized skin showing iron particles on the surfache (20 × direct X-ray magnification)

using X-ray magnification. It was also possible to demonstrate the 3-dimensional structure of the glass particles under the micro- focus X-ray-tube by rotating the object (Figs. 3, 4).

Natural leather showed some contrast using low energy imaging, but this was so weak that photographic documentation was not possible. However using the same technique synthetic leather particles gave good contrast even with very small particles of tissue (Fig. 5).

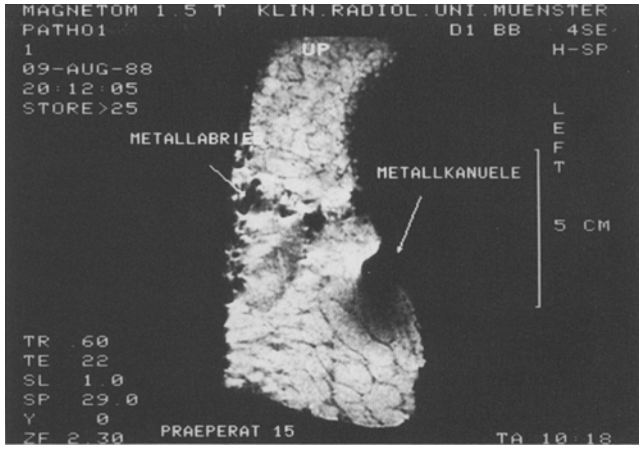

Fig. 8. Nuclear magnetic resonance technique. Ferromagnetic particles in tissue tramatized with a rusty iron rod. Loss of signal also in the punction canal of a metal needle

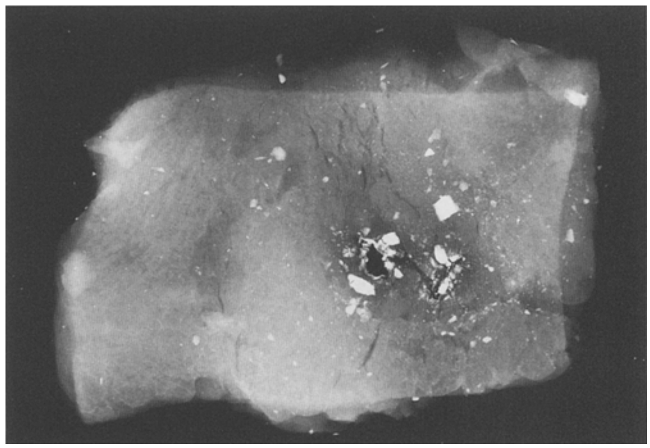

Fig. 9. Roofing tile particle in the depth of a wound (low energy X-ray imaging)

2. Skin preparations after blunt force injury

Skin which had been traumatized using a rusty iron rod was investigated for the presence of metal particles using low energy X-ray imaging as well as X-ray magnification and nuclear magnetic resonance. Metal particles were clearly recognizible with the low energy X-ray imaging and the X-ray magnification techniques (Figs. 6, 7). Clear differencies could be seen in the morphology of iron and iron oxide particles in comparison to other foreign particles especially using the X-ray magnification. Investigations using nuclear magnetic resonance (NMR) showed that a substantial number of fine rust particles remained on the surface of the traumatized skin which in the tomogram gave a deflection of the magnetic waves. This led to a loss of the corresponding signal on the screen image. A metal nail was briefly inserted in the tissue as a control before the investigations and a clear loss of signal could also be seen in the surrounding area (Fig. 8).

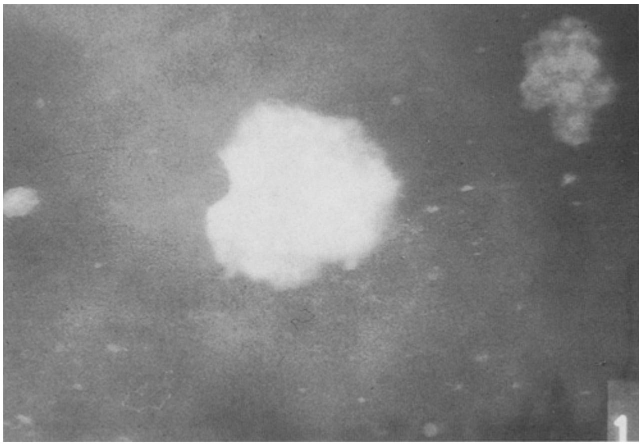

Fig. 10. 20 × magnification of cement particles by direct X-ray imaging

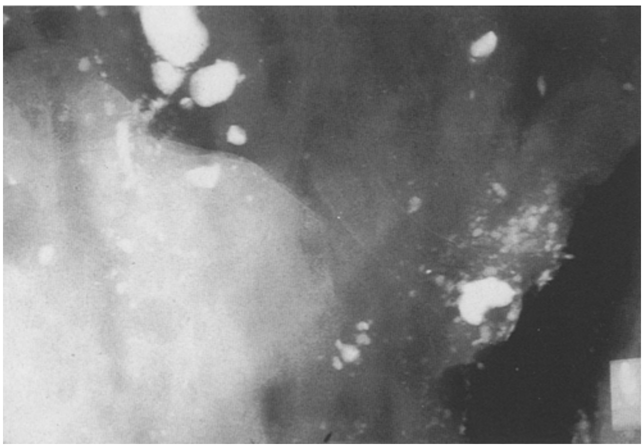

Fig. 11. Particle of red brick in a wound caused by blunt force (18 × direct X-ray magnification)

The X-ray investigations of skin preparations after the infliction of blunt force in the form of blows with various stone and concrete materials showed that concrete paving stone, roofing tiles, limestone and bricks contained contrast-giving materials. Additionally foreign bodies from every type of instrument could be found in the injuries caused by all these materials. These were recognizable using low energy X-ray imaging and microradiography methods (Figs. 9–11).

3. Skin preparations after shooting injuries

Smoke and powder components could be demonstrated in the surroundings of the entry wound using both low energy X-ray imaging and the X-ray magnification. The scanning photograph prepared using the former technique, previously allowed an impression of the pattern and distributions of particles. In injuries caused by a humane killer, the typical smoke rings were visible at an approximate distance 1,5 cm from the entry wound in all cases. The direct X-ray magnification gave information about the exact localisation and pattern of the individual smoke particles (Figs. 12, 13). Additionally the skin

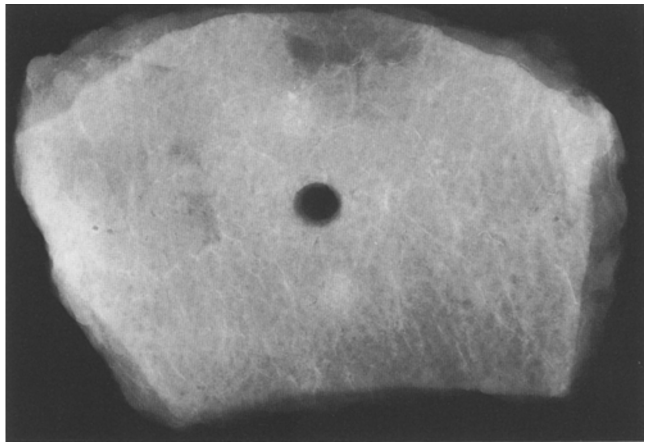

Fig. 12. Injury caused by humane killer (low energy X-ray imaging). Typical smoke residues and 2 separate smoke rings in the area of the entry wound are clearly visible

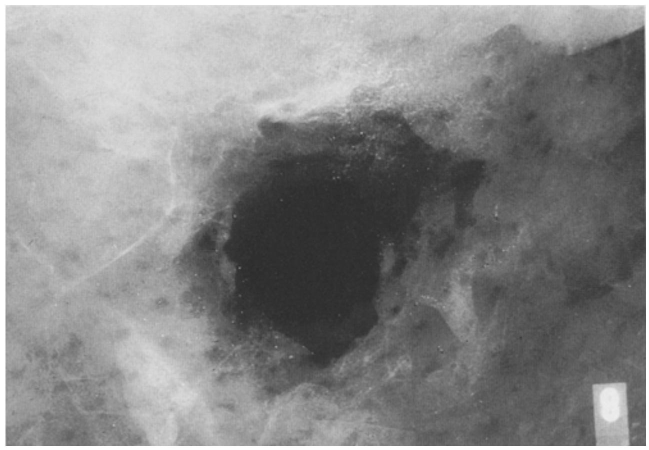

Fig. 13. Smoke residues surrounding of an entry wound by direct X-ray magnetification (3 ×)

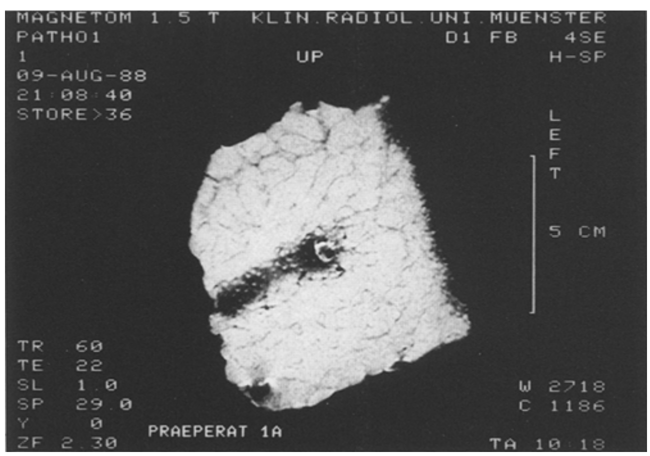

Fig. 14. Nuclear magnetic resonance image of a entry wound with ferro-magnetic substances around the perimeter and in the bullet track. Additional loss of signal surrounding the puncture mark of a needle (lower left corner)

preparations were investigated using an NMR to detect ferromagnetic foreign bodies in the gunshot wounds. Loss of signal caused by metallic foreign bodies could be seen both around the entry wound as well as throughout the extent of the bullet track. Furthermore a clear loss of signal was observed in the left lower pole of the preparation, where a nail had been used to fix the tissue preparations during the experiment (Fig. 14).

Discussion

The medico-legal investigation of wounds for contaminating foreign substances would normally be carried out optically and only by physico-chemical investigations for gunshot wounds. The optical investigation is carried out microscopically with a magnifying glass or stereo microscope. These investigations are limited by various factors: Transparent materials such as glass are difficult to detect especially when they are additionally masked by fluid and tissues (Bajanowski et al. 1991); the reproducibility is especially limited in macromorphological investigations; additionally in practice, a morphological masking occurs by crusted blood and by the infiltration of particles in folds of tissues etc. Much of the material can be washed away during the post mortem inspection by the preliminary cleansing with water. Similarly this can happen during life, when drainage of blood can wash particles away. For this reason an extension of the investigation methods can be meaningful. Obviously these also have their limitations where the effects of absorption and magnetisation have not occurred. In addition the reproducibility of the classical X-ray method is limited to partical sizes greater than 300 μm (Bajanowski et al. 1991). In recent times this method, as well as the optical investigation, has been supplemented by direct X-radiographical resolution, which can recognize particles as small as several μm (Hüttenbrink et al. 1989; Paldauf et al. 1989; Bajanowski et al. 1991).

Low energy X-ray imaging

To guarantee a suitable controle, particles greater than 1 mm in size were used for the insertion experiments. As expected the synthetic particles form the indicator and light housing could not be visualized using X-ray techniques. Negative results were also obtained for wood and leather particles. Surprisingly good results were obtained for paint and synthetic leather particles and the previously described demonstration of glass particles (Goldhahn and Buttenberg 1965; Gron et al. 1986; Bajanowski et al. 1991). Radiopaque components seem to be regularly present in all 3 materials. In blunt force injuries very different types of stone could be regularly demonstrated by a variety of stone particles. The demonstration was successful using both x-radiological methods. In comparison to mammography, an immense number of additional particles could be demonstrated using the high resolution X-ray analysis. Because similar instruments are often used to cause blunt mechanical injuries a radiological analysis is recommended for the investigation of injuries caused by unknown instruments. Whilst no radiological signal was produced in injuries caused by smooth iron rods this was successful with rusty instruments. The NMR investigation could have found a new area of application because this method seems to be extraordinary sensitive for the smallest amounts of magnetizible materials. This is most impressively recognizable in that a deletion of the signal could be recognized even in the puncture marks caused by needles. Further investigations are necessary to test the specifity of this method.

Components of smoke and powder granules which are impregnated in the skin by close-range gun shots have already been shown to give diffuse positive signals in mammography. Direct magnifying X-radiology essentially gives a more differentiated information and NMR also leads to a deletion of the signal although less detailed. As neither evidence of shooting wounds nor the determination of range present problems using physicochemical methods (Sellier 1967), an extension using the methods described can at most assist the assessment of the approximate range by semi-quantitative application to the question of close-range or far-range shooting. Although the possibilities to determine the shooting distance using X-ray imaging have been described (Böhm et al. 1969) further investigations including the new methods are necessary.

Comparison of mammography and direct resolution X-ray imaging

In the present investigation mammography and direct magnification X-ray imaging gave basically similar results. The difference corresponds approximately to that observed between macroscopy and the investigations with an operation microscope. The resolution with direct magnification X-ray imaging is approximately 1–2 degrees of magnitude higher than mammography. Therefore substantially more particles can be found in wounds with varying sizes of particles (e.g. glass-incisions, blow with stone) using direct resolution X-ray analysis, which can often occur in practice, if large particles would be washed away by cleansing or by blood drainage. Furthermore the advantage of direct magnification X-ray imaging is the possibility of observing the preparation in a 3-dimensional structure by rotation. With some experience the material properties of the particle (e.g. glass, paint) can be preliminarily located (Hüttenbrink et al. 1989; Paldauf et al. 1989; Bajanowski et al. 1991). A more precise identification of the material is only possible after removal of the particles from the wound. Determination of the origin can be carried out using specific methods such as electron probe analysis or by direct comparison with known control samples using various other methods.

Because of unknown properties of the material, particle sizes in collaboration with masking effects of blood and tissues, the detection of foreign particles in wounds or on the skin can be extraordinary difficult. This can only continuously be successful when a spectrum of several methods have been used. The direct magnification

X-ray imaging and the nuclear magnetic resonance techniques are capable of opening new perspectives for forensic application.

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