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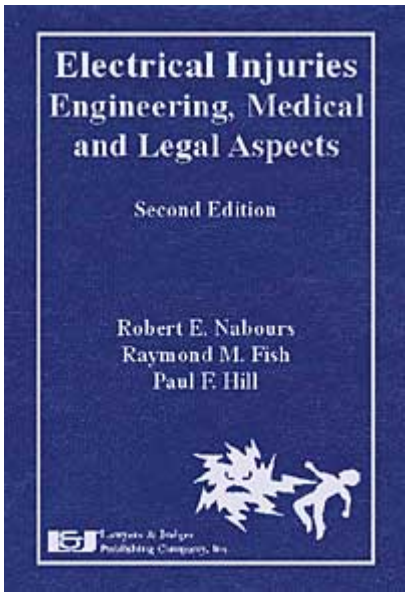
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Histopathological changes in electrocution

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Introduction

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One of the biggest challenges faced by forensic pathologists is death due to electrocution. In many cases, one can see the gross pathological findings such as Joule burns, but in many cases - almost half of all cases - no gross pathological findings can be seen, and one must rely on history and circumstantial evidence.

For quite some time pathologists have tried to diagnose electrical deaths by histopathology, but they have met with mixed success. In this short review article, a brief survey would be made of the histopathological findings in the skin in electrocution deaths.

Histology of Normal Skin

It is useful to review the histology of normal skin, before dwelling upon the histopathology of electrocution deaths. Histologically the skin consists of five layers, which from below upwards are (i) Stratum germinativum (also known as stratum basale or stratum malpighii) (ii) Stratum spinosum or prickle cell layer (iii) Stratum granulosum or granular layer (iv) Stratum lucidum or clear layer and (v) Stratum corneum or cornified layer. Of these the first two layers (S. germinativum and S. spinosum) belong to a region generally known as **The Germinative Zone** and the last three layers belong to a region known as **The Zone of Keratinization** . A few words about each layer may be in order here.

• *Stratum germinativum* - This layer is situated adjacent to a basal lamina and consists of cells which are actively dividing

• *Stratum spinosum* - This layer is several cells thick and consists of keratinocytes of prickle cells. These prickle cells are linked by numerous desmosomes, which gives it a rather prickly appearance. This layer is responsible for much of the mechanical coherence of the skin.

• *Stratum granulosum* - This layer consists of flattened cells with pyknotic nuclei surrounded by numerous basophilic granules. These granules are composed of *keratohyalin* , a precursor of keratin.

• *Stratum lucidum* - This layer is seen only in thick skin, such as that of palms and soles. It consists of closely packed cells in which traces of flattened nuclei may be seen. The cells contain the keratin precursor *eleidin* .

• *Stratum corneum* - The cells in this layer have lost all internal structure, including nuclei. The cells are full of *keratin* .

Histopathology of electrocution

Much of the studies on the histopathology of electrocution were done in the earlier part of 20 th century by the Austrian scientist Stefan Jellinek (1871-1968).[1] He began to conduct his electropathological studies in Vienna. His investigations related primarily to the accidental electrocution, clinical course and most significantly, the histopathology of the electrical trauma. He can truly be called the founder of electropathology. Before him, the prevalent belief was that the microscopical changes consequent upon electricity were mainly because of the burns (or Joule heat) produced by it. He challenged this belief and conducted several studies, by which it was conclusively proved that electrocution could produce its very own specific microscopic changes.

Streaming of the nuclei

By far the most characteristic and consistent microscopic change seen in burns is the streaming of the nuclei. The basal epithelial layers show nuclear elongation. The elongated nuclei are pyknotic and are very tightly packed. The same nuclear changes are also seen in the integumentary appendages, especially in the hair follicles. This elongation of nuclei is seen mostly in the peripheral areas of electrical injuries. Since the area of electrical injury itself is extensively destroyed, the basal epithelial layer may simply not be existing to show these changes.

Jellinek, most famous for his work on histopathology of electrocution thought that the nuclear elongation is attributable to an electric polarization effect. This position was corroborated by another scientist Heinlein in 1962.

It is important to note that these nuclear changes are seen in many other cases, e.g. blunt dermal injuries, cauterization, blisters following barbiturate poisoning and even freezing. Nuclear changes are therefore not an evidence of electrocution all by themselves. However coupled with circumstantial evidence and other corroborative evidence, they can form a very valuable and useful forensic finding.

Necrosis of cells

Pronounced necroses of cells in the epidermis and dermis is found in electrical burns. It is also thought that the extent of necrosis can be used to differentiate between burns produced by electricity and those by heat, which remains one of the central questions in forensic pathology. The borders of necrosis produced by electric current are indistinct. There is no clear cut demarcation between the necrotic and healthy tissue. Instead a *lattice like formation* is seen, which necrotic and healthy areas forming the lattice. In a way, the necrotic areas radiate into healthy areas in a branch like fashion. In contrast, thermal necrosis is sharply delimited when produced by contact heat. The necrosis in this case is said to be plate like or *patelliform* .

Metallization

Metallization of the electrical lesion, i.e. deposition of conductor metal on to the skin is quite characteristic of electrical injury. Metallic deposits in cases of electrocution were first found by Schrader in 1920 in the dermal connective tissue in the area around hair roots and in the musculature. He thought - quite correctly - that these traces arose as a result of metal transport

across the skin by the electric current. Koeppen did more work on this and found that metal could be detected more superficially too.

The visualization of this metal is important for court work and is done in several ways. One of the most popular is the one developed by Adjutantis in 1962. Dilute nitric acid is dropped on to the lesion. This brings the deposited metal into solution. The solution is absorbed by a strip of filter paper impregnated with benzoin-oxine. In this way, a distinct staining reaction takes place. The sensitivity of the acroreaction test can be increased by dithiooxamide for evidence of copper and by potassium ferricyanide for evidence of iron. The metal reagents can also be sprayed onto the sites to the investigated. Histochemical test for iron can also be done by Berlin blue reaction. An important precaution however must be followed when Berlin blue reaction is tried. In formalin fixed tissue samples, the Berlin blue stain can diffuse into the musculature, giving false interpretation. It is therefore advisable that the fixation be done in alcohol or using cryostat sections. Recently electrographic methods have also been used to demonstrate metals on the lesions.

Another good method to see metallization is the precipitation of metal as a sulfide. This is a very sensitive method and by this method, even the smallest metallic traces in the tissue can be precisely visualized. This is done by fixation of the tissue samples in hydrogen-sulfide alcohol. This method is also helpful to some extent in differentiating between burns due to electricity and those due to fire. In case of electric burns, the metallic traces are found in the peripheral areas of burns in the spaces of the integumentary appendages. Another characteristic of electric burns is the *band like and striate metallization* of upper epidermal layers. This band like and striate metallization is absent in case of burns produced by heat, where the metallization is more compact and uniform.

Surface impression of metallization may be helpful in distinguishing electrical burns from those produced by heat. In cases of electrocution, there is *non uniform distribution of metallic traces* . Small fused cavities develop at the point of current passage (due to sparking). Metal is deposited in the vicinity of these fused cavities and within the cavities (punctiform deposition of metal). Since in burns produced by heat, there is no sparking, the fused cavities do not develop and the metallization is more uniform.

Workers have tried quantitative determinations of copper in burns caused by heat and electricity so that some forensically important difference could be determined between the two. However no such differences could be determined.

Short duration currents

When the current is applied only for a very short duration, there is negligible development of heat. In such cases, following changes are most marked

- Swelling and homogenization of the local area
- Upper horny layers take histological stains more strongly
- In middle epidermal layers
- the cytoplasm of the cells is homogenized
- nuclei appear vesicular and swollen
- keratin is clumped and discolored yellow

• In the electron microscope

• Nuclei are deformed

• Contain clumped chromatin

Other changes in skin

Other important changes seen in electrocution deaths are the following. It is important to realize that not all changes may be seen in all cases.

• When strong heat develops, the epidermis is extensively destroyed

• In the peripheral areas of electric lesions, the epidermis is thickened, festoon like, homogenized and interspersed with vesicular cavities. These findings are particularly prominent when the contact sites are on thick skin such as palms of the hands and soles of the feet.

• In the wall like marginal regions of electrical burns, the lower epidermal layers appear compacted toward the exterior.

• Coagulation of keratin is seen in the corium

• Superficial carbonization is present

• Swellings of the collagenous fibers.

• Histochemically, there may be reduced activity of NAD-diaphorase, acid phosphatase and alkaline phosphatase in the epidermis and dermis. NAD-diaphorase is especially sensitive to the effects of heat.

• After prolonged current flow of more than 10 seconds, there is a positive esterase reaction outside the negative vital reaction zone.

• Hemorrhages in the corium are seen

• In scanning electron microscope (SEM) studies, of the rabbit model, thrombotic changes are seen in the vascular endothelium after a current flow lasting up to one minute.

Changes in other internal organs

Histological changes in other internal organs are not specific and must be seen in conjunction with other forensic evidence.

Cardiac muscle

There is severe damage to the muscle fibers with plaque like destruction, striate infarctions, hemorrhages, fine droplet fatty infiltrations and edema. There is fragmentation of cardiac muscle fibers, although this is thought to be perhaps a postmortem change.

In the rabbit model (rabbits killed with an AC current), electron microscopically, there is total destruction of the mitochondrial structures in the cardiac muscle tissues.

Skeletal muscle

There is contraction of the muscle fibers and compaction of the Z bands. Muscles in the path of current should be seen for these changes. Other muscles will not show these changes. Muscle fibers may be lacerated presumably due to hypercontraction due to current.

Elastic fibers

Elastic fibers in the region of electric burns show a change in birefringence under the polarizing microscope and a reduction in their resistance to digestion by elastase.

Brain

Brain shows areas of electrothermal coagulation necroses. Microhemorrhages are found in the region of the third and fourth cerebral ventricles. These microhemorrhages can be explained as the general unspecific effects due to a large increase in blood pressure.

Blood vessels

In the medial layer (mesothelium) of the walls of vessels falling in the path of the current, the nuclei undergo corkscrew like deformations, splitting and fibrous degradation. The nuclei sometimes disaggregate into several, equal sized fibrous fragments that are adjacent to each other and connected at one end. The endothelium shows cellular vacuoles and swelling. Jellinek thought that these findings are produced as a result of electric polarizing effects.

Bone

There is unspecific liquefaction and tissue discontinuity. Bone collagen is destroyed. Melting of inorganic material (phosphates) and resolidification can give rise to what is known as "bone pearls" or "wax pearls". Under the scanning electron microscope, one can identify a bricklike pattern on the surface of the liquefied inorganic bony substance.

Fluorescence microscopy of electric lesions

Fluorescence microscopy of electric lesions has been tried by Somogyi and associates. On the basis of this microscopy, they divided electric burns in three grades of severity:

- **Low severity** : In this case, the epithelium is not destroyed. There is circumscribed minimal epithelial damage and swelling of the connective tissue fibers.
- **Average severity** : In this case, there is destruction of the epidermis. Connective tissue shows swelling and homogenization. It shows increased stainability with basic stains, but with other stains, the stainability is reduced.
- **Maximal severity** : In this case, there is coagulation and homogenization of all kinds of tissue with strong cavity formation. There is loss of nuclear staining as well.

Histopathological Differences in burns produced by electricity and heat

Here is a summary of the differences between burns produced by electricity and those by heat in a tabular form for easy recapitulation.

Criteria	Burns due to electricity	Burns due to heat
Necrotic area	The necrotic area has an indistinct border with the healthy area. Lattice like formations are seen at the borders.	The necrotic area is much more sharply delimited. It shows sharp borders with the healthy tissue. The borders are said to be plate like or patelliform.
Local lesion	Small fused cavities develop, presumably due to sparking	No such fused cavities develop
Metallization	The metallic traces are found in the peripheral areas of burns in the spaces of the integumentary appendages. The metallization of upper epidermal layers is *band like and striate* .	Band like and striate metallization absent. Metallization is more compact and uniform.
Surface characteristics of metallization	Punctiform. Gets deposited in and around fused cavities	Not punctiform. More homogenous and uniform.
Skeletal muscles	There is contraction of the muscle fibers and compaction of the Z bands. These changes are presumably due to the passage of current. Muscles in the path of current should be seen for these changes. Other muscles will not show these changes. Muscle fibers may be lacerated.	No such changes are seen in any muscle.
Blood vessels	In the mesothelium of the walls of vessels falling in the path of the electric current, the nuclei undergo corkscrew like deformations, splitting and fibrous degradation. The nuclei sometimes disaggregate into several, equal sized fibrous fragments that are adjacent to each other and connected at one end. The endothelium shows cellular vacuoles and swelling.	No such changes are seen in burns.
Bone	There is unspecific liquefaction and tissue discontinuity. Bone collagen is destroyed. Melting of inorganic material (phosphates) and resolidification can give rise to what is known as "bone pearls" or "wax pearls". Under the scanning electron microscope, one can identify a bricklike	No such changes are seen in burns.

pattern on the surface of the liquefied inorganic bony substance.

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