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A study on the type of lesions achieved by three electrosurgical methods and their way of healing

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Abstract

The technical progress in the medical sector in the past decades has continuously driven the development of electrosurgical techniques. The controversies surrounding the superiority of a certain technique relative to another – electrocautery, laser and radiofrequency – have determined us to carry out a histopathological design with the aim of comparing the healing sort of the shallow wounds generated by the three types of electrosurgical devices. The experimental study has investigated the healing process inflicted by the electrosurgical devices mentioned beforehand on 12 Wistar albino rats. The wounds were inflicted under intravenous general anesthesia with Xylazine and Ketamine and were performed lateral to the spine region, using laser, radiofrequency and electric cautery. The histological samples harvested at one, three, five, and seven days were sent to pathological examination. We followed by comparison the evolution of the first two phases of the wound healing produced by the three electrosurgical methods analyzed. We described the histopathological changes occurred in the epidermis, dermis and hypodermis and also the subcutaneous soft tissues in all of the three types of lesions. Electrocautery remains the most frequently used electrosurgical device, even if it has unquestionable disadvantages as compared to other modern instruments. Laser-assisted surgery and radiofrequency are refine energy-based instrumentation, being utilized at a multidisciplinary surgical level.

***Keywords*:** electrocautery, radiofrequency, laser-assisted surgery, wound healing.

Introduction

The technical progress in the medical sector in the past decades has continuously driven the development of electrosurgical techniques, with a final purpose of improving the post-operatory results, shortening the hospital stay, and leading to a more physiological healing of the surgical wounds [1, 2].

The first steps in the development of electrosurgical devices were represented by the appearance of conventional mono- and later bi-polar cautery. This energy-based surgical instrumentation helped us to perform incisions with less bleeding but were less precise and associated significant thermal damage not only to incised tissues but also to the adjacent structures [3, 4]. The next techniques to appear, *i.e.*, radiofrequency (RF), laser and coblation, have further improved the surgical technique by reducing the thermal damage during dissection while maintaining bleeding control [5, 6].

The controversies surrounding he superiority of a certain technique relative to another have determined us to set up an experimental study with the aim of investigating the healing process of the wounds inflicted by the three types of electrosurgical devices, frequently utilized in ophthalmology, ENT (ear, nose and throat) surgery, endocrine, general and plastic surgery, *i.e.*, electrocautery, laser and radiofrequency.

Materials and Methods

The experimental study has investigated the healing process inflicted by the electrosurgical devices mentioned beforehand on 12 Wistar albino rats, aging from 10 to 12 months, from the Animal Facility of the University of Medicine and Pharmacy of Tîrgu Mureş, Romania. Because the infection of the wound would have modified the results, we chose rats as experience animals, as they are the least likely to exhibit this condition. The study has been performed in conformity with the Approval (No. 10/18.02.2009) of the Ethics Research Committee of the University of Medicine and Pharmacy of Tîrgu Mureş.

The wounds were inflicted under intravenous general anesthesia with Xylazine and Ketamine in the following doses: 0.05 mL (0.5 mg) of Xylazine and 0.08 mL (8 mg) of Ketamine were administered per 100 g of subject weight.

The dorsal skin was freed from the fur, disinfected, and three circular zones were drawn one under the other. A veterinary marker was used for delimitation of the zones where the lesions were to be applied. The rats were numbered on the tail and were processed.

After inducing the anesthesia, the rats were laid on the ventral side and the lesions were performed with the above-mentioned technique, lateral to the spine region, from superior to inferior, using laser, radiofrequency, and electrocautery. The medical devices utilized in the experiment had the following characteristics:

▪ LASER CO_2 produced by EU LASER, type CTL 1401, 10 600 nm, certified ISO 9001, ISO 13485;

▪ monopolar electrocautery produced by ERBE, type ICC 50, 10122–003, power 50 W, frequency 350 kHz, impedance 50 Ω;

▪ radiofrequency produced by CURIS® Sutter Medizintechnik GmbH (Germany), power 4.2 MHz.

The setting of devices was as follows:

▪ the laser was used at 2.5 W, continuous mode;

▪ the electrocautery was set to 35 W, "cut" mode, with monopolar end;

▪ the radiofrequency was set to 10 W.

After 24 hours, 72 hours, five days, and seven days, groups of three rats underwent local anesthesia and the histological pieces were harvested from the marked zones with the use of "cold" instruments (scalpel, scissors, forceps) (Figure 1).

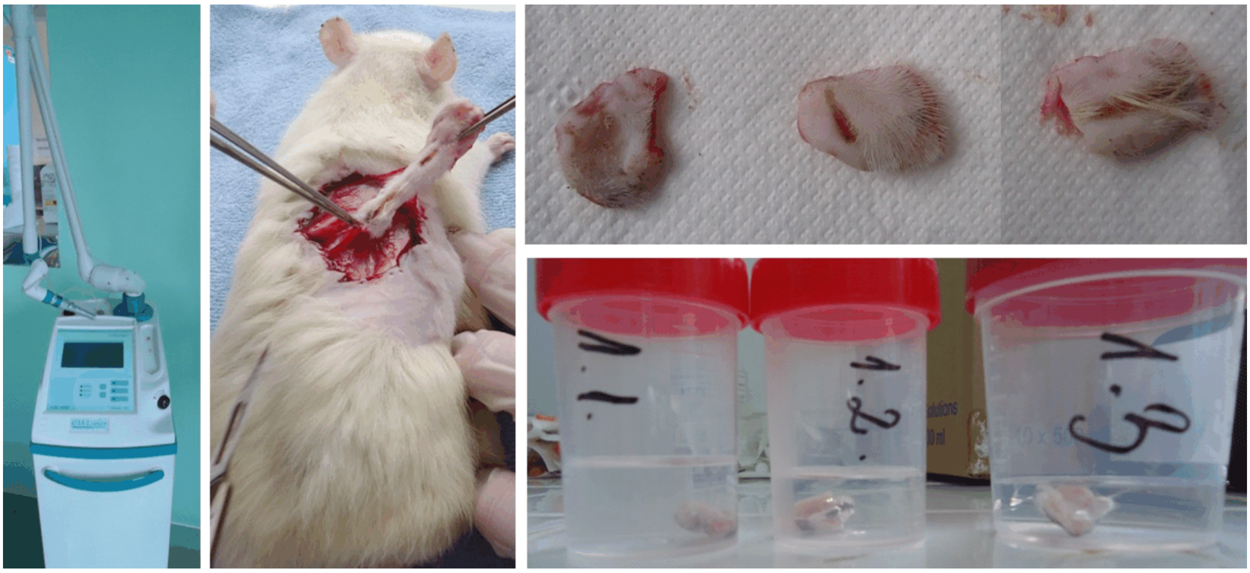

Figure 1 – *Summarizes the important steps of the experiment.*

The tissue samples were placed in 10% neutralized formalin solution and sent for pathological examination.

During the pathological examination, the tissue parts were sectioned and stained with Hematoxylin and Eosin (HE). The wounds' healing process was subsequently microscopically analyzed. The sections were scanned with a Mirax Scan System and the photos were processed by a Panoramic Viewer Software.

Results

We followed by comparison the evolution of the first two phases of the wound healing (inflammatory and proliferative phase) produced by the three electrosurgical methods (electric cautery, radiofrequency and laser). We described the histopathological (HP) changes occurred in the epidermis, dermis and hypodermis and also the subcutaneous soft tissues in all of the three types of lesions. We did not conduct any survey on the last healing phase (remodeling and scarring) because the most important changing period includes the first seven days and the number of available subjects was limited.

On the first day, the cutaneous injury produced by electric cauterization and laser looked almost similar: the electric and photon energy applied on the skin has produced focal coagulative necrosis affecting the whole thickness of the epidermis, associated with destruction of the basal membrane and almost the entire thickness of dermis and the cutaneous appendages (pilosebaceous units and eccrine glands). Therefore, there were no distinct boundaries between the epidermis and dermis, as they were replaced by a dense hyaline mass, with no distinguishable cellular components. The cell membranes of the epithelial cells were indistinguishable, with the cells presenting a more violaceous cytoplasm with inconspicuous nuclei.

The epidermal and dermal injuries produced by radiofrequency presented similar changes, but the epithelium of deep cutaneous appendages was not completely destroyed. The basal membrane and basal layers of the epithelium were intact. Near the injury, the dermis presented congestive blood vessels, which were present also in the subcutaneous muscle layer. Within the muscle layer, the presence of a discrete perivascular inflammatory infiltrate was also noted (Figure 2).

Starting on the third day, we noticed the typical changes for the proliferative phase: on the surface of the wounds, we observed the formation of a cloth, constituted by a fibrin meshwork with deposition of thrombocytes and neutrophils. The cloth was extremely prominent in the injuries produced by electric cauterization, less for laser injuries and hardly noticeable on the surface of the wounds produced by radiofrequency. The inflammatory infiltrate observed on day three is a polymorphous one, including neutrophils, which migrate first into the affected area, subsequently replaced by macrophages. The inflammatory infiltrate was more dense in the wounds produced by electric cauterization, affecting the whole thickness of the skin: epidermis, dermis and hypodermis. In the wounds produced by radiofrequency, the inflammatory reaction was localized with predilection at the deeper layers of skin: the deep dermis, hypodermis and underlying skeletal muscular tissue. The inflammatory infiltrate was present only at the edge of the wound and was localized only at the dermis in the wounds produced by laser, without affecting of the deeper layers of the skin.

Since day three, we noticed the occurrence of the reepithelialization phenomenon in the radiofrequency induced wounds. This process starts in the depth of the remaining adnexal epithelium and spreads to the surface (Figure 3).

From day five, we noticed the occurrence of the reepithelialization phenomenon in the wounds produced by laser. In this case, the wound reepithelialization starts from the periphery of the wound, as the deep adnexal structures are completely destroyed. In the depth of the dermis, a granulation tissue has been constituted with numerous neoformed, small caliber, blood vessels (capillary-like), associated with fibroblast proliferation. The capillaries were permeable, so the granulation tissue was edematous and was infiltrated by inflammatory cells. We observed that the amount of the granulation tissue has depended on the intensity and extension of the initial injury and inflammation. The lesions produced by electric cauterization were quite extensive and the epithelialization was delayed (Figure 4).

We found reactive changes in the epidermal cells: the cells were presented with higher waist, with nuclear enlargement, obvious nucleoli and the presence of mitotic figures in the basal and parabasal layer. Reactive epithelial changes were similar in all of three types of injuries (Figure 5).

Microscopic sections examined in day seven presented complete epithelialization of the radiofrequency caused wounds, but with the persistence of mild inflammation in the depth.

The lesions produced by laser were completely healed and the superficial crust formed by necrotized tissues on the surface was non-adhesive on the newly formed epithelium. The dermal vessels were still congested.

The lesions produced by electric cauterization were not healed in day seven, the epithelialization was incomplete, the abundant inflammation has persisted and it was associated with focal suppurations. The inflammation was present on the entire thickness of the skin, including the subcutaneous adipose tissue and deep muscular layers (Figure 6).

Electric cauterization **Radiofrequency** **Laser**

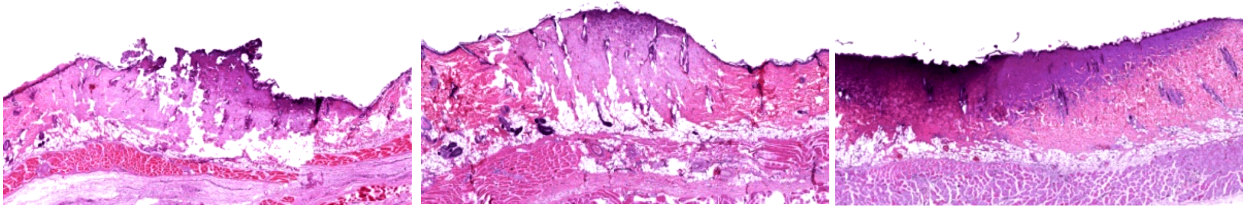

Figure 2 – ***The evolution of the wound healing produced by the three analyzed electrosurgical methods: histological aspects in day one (HE staining, ×50).***

Electric cauterization **Radiofrequency** **Laser**

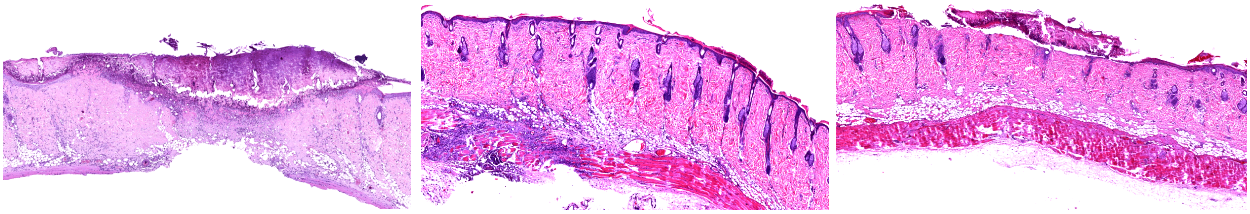

Figure 3 – ***The evolution of the wound healing produced by the three analyzed electrosurgical methods: histological aspects in day three (HE staining, ×50).***

Electric cauterization **Radiofrequency** **Laser**

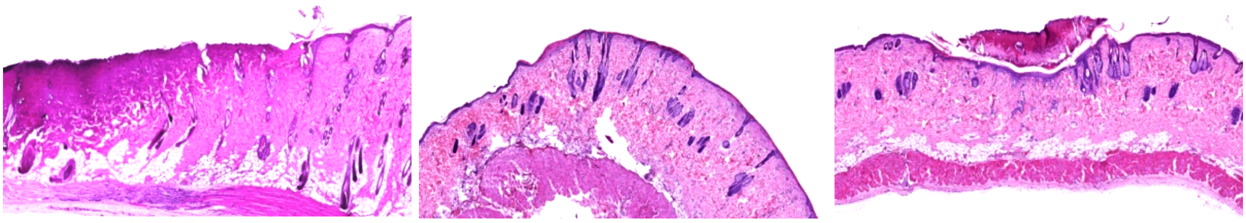

Figure 4 – ***The evolution of the wound healing produced by the three analyzed electrosurgical methods: histological aspects in day five (HE staining, ×50).***

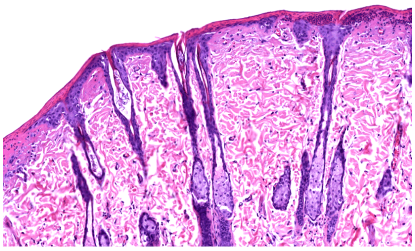

Figure 5 – ***The evolution of the wound healing produced by the three analyzed electrosurgical methods: histological aspects in day five – complete epithelialization (HE staining, ×150).***

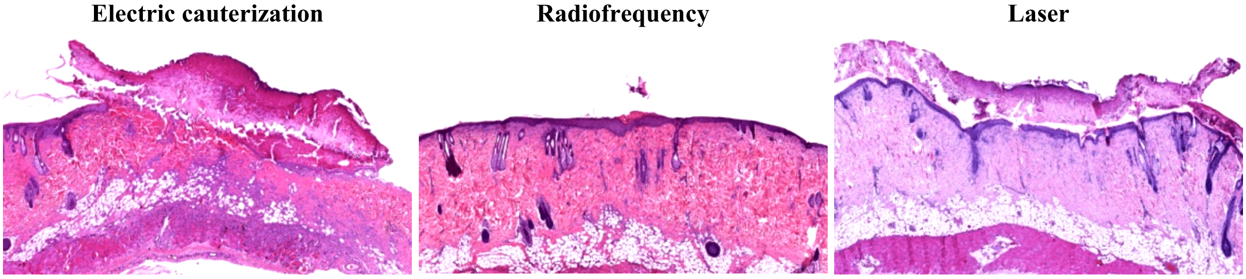

Figure 6 – ***The evolution of the wound healing produced by the three analyzed electrosurgical methods: histological aspects in day seven (HE staining, ×50).***

Discussion

The history of the medical uses of electricity is at least as old as electricity itself. William T. Bovie is credited by the majority of surgeons as the father of electrosurgery even if more rudimentary electrosurgical devices had been used well before 1920, when the previously mentioned author has developed and brought in day to day-practice the instrument which now bear his name ("bovie") [3, 7]. Since then the developments in the field of electrosurgery were without precedent; in the last 20–30 years an increasing number of energy-based surgical instrumentation were introduced in the operating room, with cauterization being unquestionable the most commonly used of the technology [8]. Thus, beside the classical "bovie", we currently use bipolar cautery, ultrasonic devices, laser and radiofrequency. Although their role in a better bleeding control and achieving hemostasis process could not be argued, their increasing number along with economical arguments were the reason of controversies regarding the superiority of one against the other concerns both the quality of hemostasis and collateral injuries to the adjacent tissues [9].

The purpose of our experimental study was to comparatively analyze the healing process of the wounds inflicted by the three different types of electrosurgical devices, *i.e.*, electrocautery, laser and radiofrequency.

Going back to basic physics, the principle of each of these instruments is based upon the transfer of the energy (electricity, wave of photons) in the tissue, which resists against this form of "aggression" by producing heat [10]. Thus, all energy devices determine a burning lesion in the target-tissue, which is described by Jackson [11] as a concentric lesion with three different zones there severeness diminishing from center to periphery, *i.e.*, central coagulation necrosis, stasis, hyperemia.

As regard, the wound healing process it is well known that it has three phases [12]. In the first two–five days, the (thermal) lesion determines a domino reaction first by activation of neutrophils and then macrophages; they release free oxygen radicals, lytic enzymes, mediators of inflammation, growth factors, which modulate the future healing process. In this period named inflammatory phase, the wound is cleaned of the bacteria and necrotized tissues and the hemostasis is achieved [12, 13]. In the next two–three weeks, the reconstruction process starts, this period being known as proliferative phase. This second period is characterized by angiogenesis, collagen sedimentation, granulation and contraction of the wound [14, 15]. Finally, the epidermal cells newly formed cover the area, process called epithelialization. In the last period, named remodeling phase or maturation, the newly formed collagen is arranged along the tension lines and the unnecessary cells are eliminated by apoptosis [16–18]. In our study, we observed only the first two phases of the wound healing process, starting from the assumption that the histological changes noted are sufficient to support conclusions regarding the differences between the three analyzed surgical instruments.

The tissue-inflicted effect produced by the classical "bovie" depends on the different waveforms delivered by the electrosurgical generators, so-called output mode [4, 5, 8]. The continuous mode or "cut-mode" produces maximum current density and delivers the greatest amount of heat over a very short time, which determines the tissue temperature to rapidly increase, subsequently with a rapid expansion of the intracellular contents and cell explosion [8]. In the interrupted mode of current delivery ("coag" mode) the amount of heat generated in the targeted-tissue is significantly lower; the tissue gradually heats, dehydrates, producing coagulation effect and finally generating a lesion comparable with a 3rd degree burn [8, 10]. In our study, we used the electrosurgical device on cut-mode power of 35 W, which determines a profound lesion extended to the deep layers of the dermis. The tissue necrosis was more extensive in comparison with the other two analyzed methods; furthermore, the inflammatory infiltrate was a lot more important as compares with the laser and radiofrequency induced lesions and extended deeply through the entire thickness of the skin. The lesions inflicted by electrocautery slowly healed, the inflammation was important and a septic complication was frequently noted. "Bovie"-type electrosurgical devices are still the most commonly used in the operating room even if they have some important disadvantages, *i.e.*, raised tissue temperatures (5000^0C), produce excessive smoke, determine a gross scarring and fibrosis, a slow healing process with possible postoperative septic complications [10].

Laser-assisted surgery was introduced in surgery in 1950s but it was extensively used in the last 20 years [19]. In short, laser-assisted surgery is also based on the thermal effect on target-tissue; due to the laser photon absorption process, the tissue temperature rapidly increases resulting in the mechanical destruction and ablation of targeted area [20]. There are two major types of lesions determined by the laser energy; in the center, where the light energy deliver is maximal, a rapidly increase of the tissue temperature above the threshold level is encountered, with coagulation, cell dehydration and vacuolization and finally, when the temperatures reaches roughly 350^0C, carbonization [19, 21]. The result is a central cavity zone, its dimensions being directly related with the technical qualities of the laser delivery system. The cavity zone is surrounded by a coagulation area, generally with a similar shape, proving the extension of the laser-energy effect beyond the target area. Raising temperatures have the same lethal effect on the tissues of this peripheral area when they reach the critical, threshold level; the rapidity with which the critical level is reached is related not only with the tissue temperature but also with the time of exposure which means that o long time exposure needs low temperatures to reach the critical level of tissue destruction [19, 22–24]. In this study, the lesion inflicted by the laser device was deep, the necrosis being extended through the entire epidermis, destroying the basal membrane, almost entire dermis and cutaneous appendages being similar with that produced by electrocautery. In our opinion laser device has some important advantages over the electrocautery; first of all the inflammatory reaction, which characterize the first phase of the healing process is less important, the granulation appears quickly but the epitelialization is delayed in comparison with lesions inflicted by radiofrequency.

Radiofrequency is a refined type of surgery which was first used in ENT surgery for the treatment of snoring [25] afterwards extending its indication in other surgical fields [26, 27]. Basically, the method uses a wave of electrons at high frequencies (2–4 MHz), similar with those used in broadcasting, thus explaining the frequently terminological confusions [28]. In opposition with the other analyzed electrosurgical methods, RF works at low temperatures, below 1000^0C, thus limiting the heat dissipation and damage of the nearby tissues [29, 30]. The lesion inflicted by RF is more targeted and precise, the granulation process starts quickly and the wound heals rapidly with a soft scar [31, 32], as we also observed in our study. We noticed that the wounds produced by RF are less profound, preserving the basal membrane and deep layers of the epithelium. Even if in RF inflicted lesion the inflammatory reaction was more important than in laser wound, the reepithelialization appeared early (day three) and was completed in day seven. Due to its unquestionable advantages, the RF device found its application in numerous surgical fields, *i.e.*, ophthalmology, plastic surgery, gynecology, general and oral surgery, etc. These RF devices can achieve simultaneous cut and coagulation, as compared with "bovie", which requires different modes and adjustments for different applications [33], or laser, which is used mainly as a cutting instrument [20]. Radiofrequency produces less smoke than electrocautery [33] and laser [9, 20], sterilizes the tissues under application, it is a less expansive energy device as compared with laser [9, 20].

Conclusions

Despite the fact that electrocautery remains the most frequently used electrosurgical device, it has unquestionable disadvantages as compared to other modern instruments. The wounds made by electric cauterization heal later ("*per secundam intentionem*") and so the wound is exposed to infectious agents that may lead to such complications in some stages. That is why his use in the future within different surgery fields, for better aesthetic, functional and economic results, must be slowly reduced to the aimed cases. Laser-assisted surgery and radiofrequency are refine energy-based instrumentation, being utilized at a multidisciplinary level, their surgical applications are complementary, being utilized together or separately depending on the surgical target. The most important practical conclusions are that for the best esthetic results on the skin, the laser is recommended, whereas for the reinforcement of the soft tissues, the radiofrequency is preferred as first choice.

Conflict of interests

The authors declare that they have no conflict of interests.

Author contribution

Gheorghe Mühlfay and Karin Ursula Horváth have equally contributed to this work and would like to share first authorship.

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