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REVIEW ARTICLE

Radiofrequency surgery: 3500 years old and still young

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ABSTRACT

Purpose: To review the history of Radiofrequency surgery, delineate the actual situation and describe the applications in eyelid surgery.
Design: Review.
Methods: Review of literature, personal communication with several pioneers in the field, and own experience.
Conclusion: Radiofrequency surgery has evolved from rude burning to a sophisticated surgical technique.

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History: From cautery to radiosurgery

Already a few thousand years ago, wounded soldiers were treated by pouring boiling oil into the wound to arrest bleeding. This application of 'cautery' appears in ancient Indian medical writings like Atharva-Veda, Choraka, and Sushruta. The dates are not completely certain, but may be anywhere around 1500 BC. The same Indian writings report the use of a sort of cautery to destroy breast lesions.[1] Hippocrates himself (around 400 BC), advised to use cautery to destroy lesions, if other methods failed. The eruption of Mount Vesuvius in 79 AD was key to preserve a lot of surgical instruments of ancient Rome. They now give us an idea about the medical knowledge at that time (Figure 1).

In ancient China, already 2000 years ago, Moxa, a dried plant (*Artemisia argyi*), was used to heat and stimulate acupuncture points. The process is called *moxibustion* and this kind of therapy has been in use as adjunctive technique during acupuncture sessions ever since.[2] In so called 'direct moxibustion', a small, cone-shaped amount of the plant is put on an acupuncture point and then burned. This direct moxibustion is further divided into a scarring and a non-scarring subtype. With scarring moxibustion, the moxa is placed on an acupuncture point to burn until it causes blisters and scarring down to a deep second degree burn. With non-scarring moxibustion, the burning Moxa is removed before it actually scars the skin.[2]

The use of hot oil for coagulation to stop bleeders was used until in the 16th century. Ambroise Paré (1510–1590), a French barber surgeon and a pioneer in surgical techniques and battlefield medicine, still used boiling oil. Although he used a cauterizing iron to stop the bleeding when amputating limbs, for other wounds, he sometimes poured boiling oil in the wound, such as in cases of bullet wounds. Gunpowder was thought to be poisonous and the oil was hoped to destroy the poison. One day, Paré had to treat more patients than he had oil for, and he experimented with an old Roman recipe. He used a cocktail of oil of roses, egg white, and turpentine. The next morning the soldiers treated with hot oil went very bad and some had even died during the night. But the men treated with Roman ointment were well rested, their wounds calm and even beginning to heal. Then he continued with this approach to sealing wounds, rather than the usual method of cauterizing wounds.[3] In 1791 Luigi Galvani was the first to demonstrate that an electric current can activate muscles. As in a lot of other famous discoveries, the correlation between electricity and muscle contraction was discovered 'by accident'. The legend goes that Galvani was skinning a frog at a table, where he had been conducting experiments with static electricity by rubbing frog skin. When Galvani's assistant touched the exposed sciatic nerve of the frog with a metal scalpel that had picked up a charge, he saw sparks and the dead frog's leg kicked as if in life.[4] In the scientific literature, we find that already in 1780 Galvani discovered that two connected different metals

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Figure 1. Cautery instruments from 79 AD. Courtesy of historical collections & services, Claude Moore health sciences library, University of Virginia.

Figure 2. McIntosh diathermy with adjustable frequency and Tesla coils (From the collection of John Abele with kind permission of John Abele and Steven D Schwaitzberg).

Figure 3. Liebel-Flarsheim "Bovie" (From the collection of John Abele, with kind permission of John Abele and Steven D. Schwaitzberg.

(e.g. copper and zinc) at the same time touch two different parts of a frog leg's nerve, make the leg contract. He called this phenomenon "animal electricity".[5] The voltaic pile, invented by Alessandro Volta, a contemporary and friend of Galvani, consists of a pile of cells similar to the galvanic cell. However, Volta built it entirely out of non-biological material. Indeed, the Volta cell essentially consists of two different metals connected by a salt bridge, or individual half-cells separated by a porous membrane.

The first monography on the application of electrical current in surgical interventions was published in 1854 by Dr. Albrecht Theodor Middeldorf.[6(p.1824–1868)] Middeldorf used the term 'galvanocautery' that he described as a procedure in which especially constructed thin platinum wires were transformed into glowing heat by a galvanic current from a zinc-platinum-battery. Thanks to this procedure, it was possible to perform dissection and destruction of tissue and coagulation of bleeding vessels for hemostasis during surgery. About a century later, Grenet introduced his single-element battery source with flasks of varying volumetric capacity, from 1/3 liter to 3 liters. His invention was published in 1885 in the Journal 'Electrical Review'.[7] It was this type of battery that was used by Paul Broca for his so called "electric knife". He modulated the electric current to the blade and in this way, he was able to change the temperature of the blade. This was achieved by lifting the plates of the battery more or less out of the salt solution. It was Antoine Séré, a French military surgeon, who in 1862 developed the housing for this battery with changeable power and to connect it with a kind of pedal to facilitate its use.[8] Thanks to these modifications the temperature of the blade could be altered between 600 and 4500 degrees Centigrade. Modern diathermy with high-frequent alternating current was introduced in medicine by the German Dermatologist Dr. Franz Nagelschmidt from Berlin. In 1913 he published his 'Lehrbuch der Diathermie'.[9] William T. Bovie introduced the "Bovie" electrosurgical device in the 1920's. In the beginning, its main use was primarily for coagulation.[10] At that time other devices used Tesla coils with exposed spark gap generators (Figure 2–3). Bovie was the first to develop an electrosurgical unit that provided not only coagulation, but also cutting settings. He was the son of William Bovie, a farmer physician. To avoid confusion with his father the insertion 'T' was added as surname prefix. What the 'T' stands for still is a well-kept secret. He discovered that electric current above certain frequencies could cut tissue without inducing muscular contraction. The first units were hand-held via a pistol-grip, allowing easy manipulation by hand activation. The electrodes were interchangeable.[11] Dr. Harvey Williams Cushing,

a neurosurgeon whose name is associated with Cushing's disease, popularized the electrosurgery machine. Cushing is known as "The Father of Neurosurgery." He incorporated electrosurgical techniques in neurosurgery. Cushing's crucial collaboration with William T. Bovie and his electrosurgical apparatus allowed him not only to operate in patients whose tumors had been previously described as 'inoperable'. In 1926, Cushing had been unsuccessful in removing a mass from a patient's head due to extensive bleeding. However, a few days later he did a re-intervention, using the Bovie unit. In his notes from that day he wrote, "…with Dr. Bovie's help I proceeded to take off most satisfactorily the remaining portion of tumor with practically none of the bleeding which was occasioned in the preceding operation."[12] Dr. Bovie sold the patent to the Liebel-Flarsheim Company symbolically for only one dollar. They began producing the unit under the Liebel-Flarsheim name. This was an electrosurgery unit that was marketed exclusively to U.S. hospitals and only in 1965 variations of the original Bovie were commercially sold (Figure 4). From that year on, the Hyfrecator and other low frequency-high temperature devices were being marketed to office practices for coagulation of bleeders (Figure 5). In Europe those units were called Diathermy. In order to increase sales, some of these companies claimed cutting ability and produced wire electrodes such as loops.

Irving Ellman, a dentist and electronic engineer at UCLA School of Dentistry, began to use electrosurgery devices in dentistry. At UCLA, he had a close friend John Flocken who was head of the Oral Surgery Department and Biomedical Engineering Department. The electrosurgery companies realized that, if they could convince dentists to use the electrosurgical

Figure 4. Liebel-Flarsheim short wave radiofrequency generator from the 1930s (From the collection of John Abele with kind permission of John Abele and Steven D. Schwaitzberg).

Figure 5. The Birtcher Crusader developed in the 1930s, a forerunner of the Hyfrecator (From the collection of John Abele, with kind permission of John Abele and Steven Schwaitzberg).

machines, their selling markets would increase exponentially. Indeed, at that time there were over 100 thousand dentists in the U.S., all in private offices and all did surgery. So several electrosurgical companies gave units to the dental schools to try on patients. UCLA School of Dentistry was one of them. Flocken discussed it with his friend Irving Ellman. Both knew that, if electrosurgery worked well in the oral cavity it would be a huge improvement to be able to gently cut gum tissue and to control bleeding in the mouth. However, as Flocken began to use the electrosurgery machines that were given to the dental clinic he noticed that these units burned the thin gingival tissue to a crisp.[13] In Flocken's words: 'These machines were a disaster in the dental cavity'. He wrote letters to other Universities cautioning them to not use these medical electrosurgery machines on gingival tissue and gave lectures showing the destroyed oral tissue after electrosurgical use. Other professors joined in warning the dental profession against its use. In less then 1 year the dental profession completely banned electrosurgical machines for dental use. The gingival tissue around the teeth is extremely thin, almost transparent. When it was burned it looked very ugly, when the patients smiled. Ellman asked his friend Flocken to send him the banned electrosurgical machine, so he could evaluate it and do further tests on this device. In the late 1960s Irving Ellman worked in the laboratory with a Variac. This electronic device allows one to vary the frequency for testing frequency purposes. He noticed that 4 MHz was the optimum frequency that produced the smoothest cutting effects on the tissue at the lowest temperature.[14] More tissue alteration was seen as he went beyond the 4 MHz. However, at that time it was not possible to build a device that would be fixed at 3.8

or 4 MHz. So the next best choice was to use the strong vacuum tube and design a circuit around the vacuum tube power source. Ellman also realized that the electrosurgical machines were too large and bulky to fit well in a small dental operatory. He took advantage of the new miniaturized electronic components. Small portable radios were becoming popular around that time. In 1973 Dr. Irving Ellman issued patents on a unit with a vacuum tube. It was the Dento-Surg Radiosurgical device. It was mainly a 90 Watts, 3.8 MHz device with three currents with a different waveform. In a further effort to get different results on tissue then he had discovered that by changing the waveforms and he could further reduce the temperature and improve the histological effect on the tissue:

- The Fully filtered waveform was developed by using a series of rectifiers. It gave 90% cutting and only 10% of coagulation.
- Fully rectified: 50% cutting and 50% coagulation
- Partially rectified: 10% cutting and 90% coagulation.

This unit is distributed today by Ellman for Dentistry. This Dento Surg formed the basic design of the Surgitron (see below), a device still being sold today.

Several of the Dento Surg units were sent to UCLA for Dr. Flocken to evaluate in the dental clinic. He studied tissue shrinkage, tissue alteration, healing, postoperative pain, cosmetic effect, and many other tissue parameters. He compared everything to the scalpel and other gold standard taught tools for altering and removing gingival tissue.[13] In the same year, Jon Garito, began working with Ellman when he was in college (Figure 6). Garito had married Ricki Ellman, Irving Ellman's daughter in 1972. Jon Garito started law school, but found that he loved working at Ellman Dental Mfg., and continued combining work with law school. During the course of the next year, Irving Ellman was diagnosed with colon cancer and he passed away in 1975. Jon Garito stepped in and took over the business. In the same year, Garito went to UCLA to work with Dr. Flocken in the Oral Surgery department and the Biomedical department. He assisted Dr. Flocken with many experiments and studies and worked with biomedical engineering professors and graduate students. He also joined Dr. Flocken for most of his over 1000 lectures at every dental school in the U.S. Internationally he was invited to give lectures and workshops at congresses and in Universities. These continuing education courses included hands-on workshops, where calf mandibles would be used to simulate the oral cavity. Dr. Flocken designed a Radiosurgery hands-on pre-surgical workshop for dentists. His workshop syllabus was later changed to reflect the different medical specialties Radiosurgery applications. The basic pre-clinical steps of the hands-on workshop was kept the same and is still used today to teach doctors how to start using the Radiosurgery device.

At this same time, Dr. Arthur Goldstein from Monaco, introduced the name 'Dento-Surg Radiosurgery' to avoid confusion with the earlier tissue destroying electrosurgical machines[15] (Figure 7). In 1978, Jon Garito introduced the Radiosurgery unit to the Veterinary market. Dr. Bob Altman a Professor at University of Pennsylvania School of Veterinary Medicine began publishing articles on its use in small

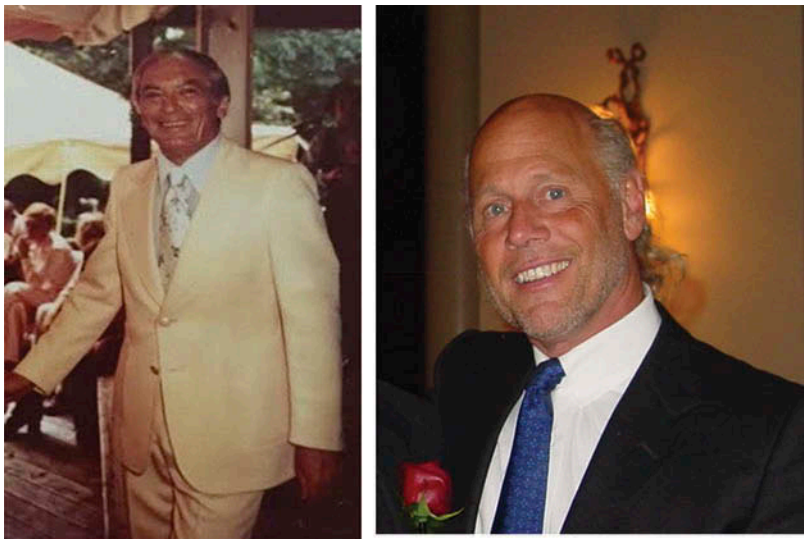

Figure 6. Dr. Irving Ellman (left) and Dr. Jon Garito (right) (courtesy of Dr. Jon Garito.

Figure 7. The Dento-Surg from the 1970s.

Figure 8. The surgitron FFPE from the 1980s.

animals and later large animals.[16] Dr. Garito designed a new circuit, which increased the power, making it more robust for the larger animals. The higher powered RF device was named Surgitron (Figure 8). In 1981 with the encouragement and support of Dr. Sheldon Pollack, head of Dermatology at Duke University, Radiosurgery entered the Dermatology market.[17] He had taken a Dental Radiosurgery course and then adapted the training manual to Dermatology. He used this Radiosurgery syllabus to teach courses at Duke University's Dermatology department.

The first use in Gynecology was in 1987. Sheldon Weinstein, gynecology professor at the University of Texas began performing cervical biopsies with excellent results and significant advantages over cryosurgery and lasers.[18] Around 1984, Dr. Garito met Stephen Bosniak, an oculoplastic surgeon in New York. He was the first Oculoplastic surgeon to use Radiosurgery in. 1985[19] Stephen Bosniak was a good

Figure 9. Stephen Bosniak and senior author Peter Raus after Radiofrequency surgery in New York in May 1996.

colleague, friend, and teacher of the senior author of this review[20] (Figure 9). ENT followed with the support of Klaus Vogt[21] and Mahmoud Moravej; plastic surgery with Randolf Waldman in. 1990[22] In 2000 Radiosurgery entered Family Practice with Jack Pfenninger, a professor of Family Practice at the University of Michigan, Podiatry with Walter Gursky, University of Connecticut and Plastic Surgery with Albert Hofmann in Germany.[14] Finally in 2005 Neurosurgery and Pediatric Neurosurgery followed with James Goodrich who separated the head-joined twins Carl and Clarence Aguirre, Steve Schneider and Anders Cohen.[23] In 1995, the first 4 MHz unit was developed as it had appeared to give better surgical results with a finer cut and less lateral heat spread in the tissues. Garito also discovered the importance of the specific material and size of the electrodes. So it was both the development of the optimum RF energy source and innovative RF electrode designs that worked in tandem to provide surgeons with the improved surgical outcomes. Garito patented over 150 Radiosurgery accessories as well. In 1997 the manufacturer Ellman switched from a vacuum tube to a solid state microprocessor. At that time an important competition was going on in Europe and many other countries. Europe had introduced the new regulations by the International Electrotechnical Commission (IEC). Up to that point, all countries relied on U.S. FDA regulations. So, with an FDA approval medical devices could be distributed internationally. However, the IEC regulations posed many technical problems for manufacturers. One was leakage current of the original vacuum tube unit. Other points of discussion were the type of connection plugs, the antenna plate and many others. These were mainly safety issues that were raised due to the problems that in the first place occurred in the OR's with the larger surgical devices.

However, rather than separate the large Electrosurgical Units from the smaller powered devices, all were grouped together. That is why the original RF unit had to be redesigned. That was the genesis of the Dual Frequency device. Because, there are also advantages to the lower frequency in coagulation of bleeders, not only the 4 MHz but also the 1.7 MHz frequency was included. The Dual Frequency device met the IEC regulations. Indeed, because sometimes a more coagulating current can be very useful to perform surgery in more vascularized areas, several RF machines offer 2 different types of current or different frequencies to work with. This Dual Frequency RF device invented by Dr. Jon Garito was granted a U.S. and International patents in 1999. The 4 MHz RF devices produce less tissue alteration then the 3.8 MHz RF tube devices. For this reason, it was ideal for the Neurosurgical and Spine procedures. The most recent modification is a 4 MHz, 500 KHz, portable wireless Radiowave device (patent pending). The most important advantages of this new unit can be:

- Reduction of the power of the unit,thanks to less loss of signal over the cable between the unit and the handpiece,
- no antenna plate needed,
- less interference with other electronic devices in the OR.[14]

Conclusion

The basics of Radiofrequency surgery go back to 3500 years ago. The technique has evolved from rude burning to a sophisticated surgical technique with further innovations expected for the near future.

Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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