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Tissue Penetration of Bipolar Electrosurgery at Different Power Settings

Rupert Ricks[1*], Suzanne Hopcroft[2], Manish Powari[3], Andrew Carswell[4] and Phillip Robinson[5]

[1]Department of Ear, Nose and Throat, Royal Devon and Exeter Hospital, Exeter, EX25DW, England.
[2]Gloucestershire Cellular Pathology Laboratory, Cheltenham General Hospital, Sandford Road, Cheltenham, GL53 7AN, England.
[3]Department of Pathology, Royal Devon and Exeter Hospital, Exeter, EX25DW, England.
[4]Department of Ear, Nose and Throat, Great Western Hospital, Swindon, SN36BB, England.
[5]Department of Ear, Nose and Throat, Bristol Royal Infirmary, Bristol, BS28HW, England.

Authors' contributions

This work was carried out in collaboration between all authors. Author RR designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SH and MP performed histological assessment for the study. All authors read and approved the final manuscript.

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ABSTRACT

Introduction: Bipolar electro-surgery is used in all disciplines of surgery to aid in haemostasis. Although common sense dictates tissue penetration will be effected by power settings, no formal evaluation of this effect has been made. We performed an experiment to accurately measure the tissue penetration of bipolar diathermy at different strengths.
Materials and Methods: Laboratory study using a porcine liver model. Different wattages (10–40 W) of bipolar electro-surgery were applied to deceased porcine liver, with and without fascial covering for a fixed duration. The tissue penetration was measured with a light microscope in two planes, horizontal and perpendicular. The data was compared with a Spearman Rank correlation coefficient calculation.
Results: For both fascia and non fascia covered liver there was a statistically significant correlation

**Corresponding author: E-mail: rupertricks@nhs.net, rupertricks@doctors.org.uk;*

between increasing power and superficial spread of tissue penetration (Non fascia rho=0.3604, p =0.05) (Fascia rho=0.893, p =0.0068). No such correlation was noted between burn depth and wattage (Non fascia rho=-0.75, p =0.93) (Fascia rho = 0.714, p = 0.0713). There was a statistically significant correlation between the diameter and depth of tissue penetration for fascia covered tissue (rho 0.893, p = 0.0068) but not for non fascia covered tissue (rho 0.3604, p =0.42).

Discussion: There is a clear relationship between the power setting of electro surgery and superficial spread of tissue damage however the effects of power setting and deep tissue penetration are not so clear. Interestingly, maximum tissue effects were not encountered at the higher power settings but between 20 and 30 W.

Keywords: Electro surgery; animal model; medical device safety; haemostatic techniques.

1. INTRODUCTION

1.1 Background

Heat has long been known to cause coagulation and haemostasis. The first recorded use is approximately 3000 BC in ancient Egypt. Developments in the generation of electricity led Morton to produce a high frequency current that caused no muscular contraction or pain and caused tissue warming [1]. This was followed in 1890 by d'Arsonval, who discovered currents as low as 10 kHz did not cause muscular contraction in human subjects [2]. Following adaptation of d'Arsonval's techniques Oudin was able to generate an electric current that caused localised tissue destruction without tetanic effect. Further developments were made in the ensuing twenty years. In 1897 Nagelschmitt coined the term *diathermy* to describe the tissue heating effects of electrical currents [2]. By the late 1900's Doyen had discovered the application of a grounding plate enabled safer use of electrosurgery by avoiding sparking to bystanders! It also allowed greater tissue penetration and direct coagulation [3].

It was in 1926 that the first electrosurgical unit that modern surgeons would recognise was developed and used. William T Bovie of Harvard University had created an electrosurgical device that allowed use of both cutting and coagulation currents [1]. This was discovered by Harvey Cushing and used by him in his neurosurgical practice to favourable effect [4]. The basic principles of electro surgery have remained unchanged since then. The electro surgery device consists of a transformer that converts mains electricity to the desired voltage. This is then passed to an oscillator consisting of silicon semiconductors that produce current of the required frequency before being passed to the first of two electrodes – the treatment electrode [1]. This enables the precise application of current to tissues before the current is returned through the tissues to the indifferent, or grounding, electrode. This can be either at a distant site, as in monopolar electro surgery, or locally as in bipolar electro surgery. Heat is generated by the action of tissue resistance impeding the flow of current and is proportional to resistance and the square of the current ($dQ = i^2 r dT$) where dQ is heat generated measured in joules, i is the current measured in amps, r is the resistance measured in ohms and dT is the time in seconds. Typical tissue resistance is 100–1000 ohms [5]. The two principle actions of electro surgery are *cutting* and *coagulation* [6].

The precise tissue effects depend on two factors – the current waveform and current density i.e. the amount of current passing through a given volume of tissue. If a high current density is achieved then a large amount of current is localized over a small tissue volume, localizing the heating effects and creating rapid tissue vaporization. This is the cutting function. The tissue is rapidly heated and reaches vaporisation point (100℃ for water) where the intracellular fluid vaporises and causes cellular explosion. Tissue separation is achieved along the incision line precisely adjacent to the treatment electrode. If a low current density is achieved then coagulation will occur. The lower current density does not achieve the rapid tissue heating of cutting density and tissue temperatures of 50–70℃ are sufficient to cause intracellular protein denaturisation. This creates a viscous coagulum that obstructs blood flow resulting in haemostasis. Current waveform is the second decisive factor. The current produced by electrosurgical apparatus is sinusoidal in pattern. An unfiltered waveform is not uniform and contains waves of varying amplitude – some reaching the required amplitude for action and some not. When employing the cutting action the waveform is filtered to eliminate low amplitude waves thus delivering the highest amount of heat to the tissues with each wave. This enables the rapid attainment of vaporization required for tissue division. For coagulation the wave is not only unfiltered but the oscillator actively dampens the waveform to produce waves of varying amplitude. This means only a very few individual waves have the energy to cause tissue vaporisation but taken as a complete waveform there is sufficient energy to cause protein denaturing and therefore coagulation and heamostasis [1].

Experimental data has shown bipolar electro surgery certainly extends beyond the tissue between the two electrodes – exposing surrounding tissue to potential thermal damage and unwanted morbidity. Maddox et al demonstrated thermal injury extending on average 2.4 mm beyond irrigated bipolar devices in the human prostate [7] with no difference between two different power settings. Riegel et al. demonstrated a tissue penetration of 1.8 mm for a bipolar ablation technique again with no significant difference between power settings [8]. In a comparison of 3 different coagulation techniques Apple white demonstrated classical bipolar electro cautery had lower surrounding tissue temperatures at 1 mm than either ultrasound or integrated devices. They still found average temperatures of 81.4° only 1 mm from the bipolar electrodes [9]. In contrast to Maddox and Riegel, Jazrawi et al. clearly demonstrated greater tissue penetration of thermal energy with increased bipolar power, although they only tested two settings [10]. Shellock and Shields were also able to show increased surface temperatures on bovine cartilage with increased power settings of bipolar electro cautery [11]. Apart from power settings duration of energy application also seems to increase thermal penetration of surrounding tissues with Lu and Habermann [12] both identifying increased duration independently increased the thermal effects in surrounding tissues.

1.2 Clinical Problem

Despite the body of evidence that shows bipolar electro cautery affects surrounding tissues there is currently no data published that directly links a range of power settings of bipolar electro-surgery to its tissue effects. Furthermore there has been no attempt to define any potential correlation between power setting and depth of tissue penetration. Surgeons are using a potentially hazardous medical device without the evidence base to inform its safe application. Although common sense would tell us the greater the power settings the greater the tissue effects we seek to formally assess the correlation between these two variables and to provide an internal schema for the practicing surgeon to apply to their use of electro-surgery.

2. MATERIALS AND METHODS

Fresh, porcine liver was purchased from a domestic butcher and divided with cold steel into individual samples with a homogenous structure and size. There were two types of liver tested; with a fascial covering and without. Each individual sample was subjected to two seconds of bipolar diathermy at a single current level. Seven current levels were measured in total, with five watt increments from ten watts to forty watts. Separate tissue samples were used for each level of current to avoid confusion with results and three samples were taken at each power setting. Once taken the samples were labelled in such a way to single blind the reporting pathologist.

The bipolar forceps were fixed at two millimetres apart and cleaned between each use with 0.9% sodium chloride solution. The tips of the forceps were gently applied to the surface of the tissue in a vertical plane before the current was initiated, the tips of the forceps remained in contact with the samples until the current was stopped after two seconds. The samples were then fixed in formalin and processed for histological assessment. A trained clinical pathologist examined the tissue using light microscopy to measure the true histological tissue penetration of the bipolar electro-surgery in two planes, horizontal and perpendicular (depth and diameter).

3. RESULTS

In all 42 samples were taken. Three at each of seven power settings, from 10 W to 40 W in 5 W increments. The tissue penetration was measured in two planes and the average of the three samples calculated.

3.1 With Fascial Covering

Spearman's rank correlation coefficient was calculated for power/depth, power/diameter and depth/ diameter. A statistically significant correlation was noted between power setting and the diameter of tissue penetration, rho = 0.893 (p = 0.0068). The comparison of power setting and depth of tissue penetration was not statistically significantly, rho = 0.714 (p = 0.0713). A significant correlation was noted between depth of burn and diameter of burn, rho = 0.893 (p = 0.0068). It is interesting to note that maximum tissue penetration in both planes occurred at 30 W.

3.2 Without Fascial Covering

Again the Spearman rank correlation coefficient was calculated for power/depth, power/diameter and depth/diameter. Once again there was a statistically significant correlation noted between power and the diameter of the superficial burn, rho=0.3604 (p=0.05). However this time there was no significant correlation between the power and depth penetration, rho=-0.75 (p=0.93), or between depth of penetration and superficial spread, rho = 0.3604 (p = 0.42). Again it is interesting to note that although there is much less correlation without a fascia covering the general trend is of increased penetration up to 20-25 W before penetration becomes reduced.

Table 1. Results with fascial covering

Power setting	Average depth (mm)	Average diameter (mm)
10 W	0.026	0.65
15 W	0.056	1.017
20 W	0.406	1.73
25 W	0.673	2.016
30 W	0.79	2.43
35 W	0.493	2.276
40 W	0.62	2.386

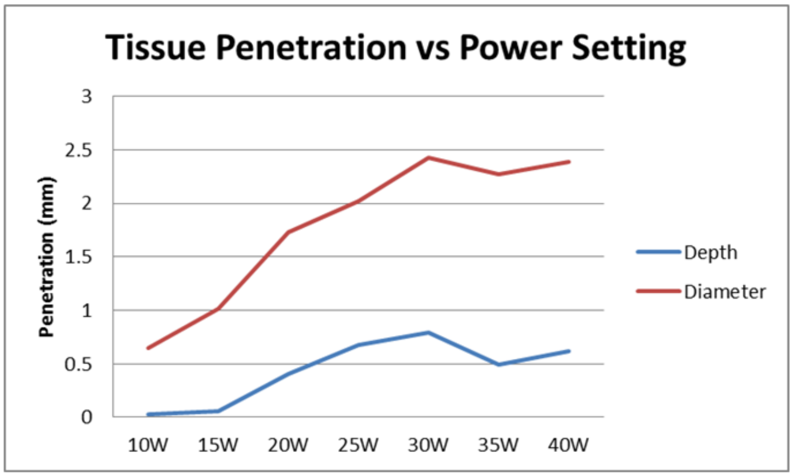

Fig. 1. Penetration model with fascial covering

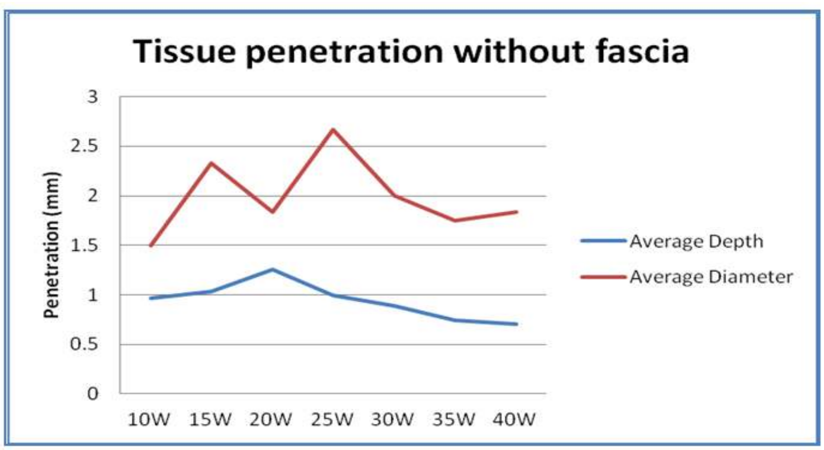

Fig. 2. Penetration without fascial covering

Table 2. Results without fascial covering

Power setting	Average depth (mm)	Average diameter (mm)
10 W	0.962	1.5
15 W	1.036	2.333
20 W	1.259	1.833
25 W	0.999	2.667
30 W	0.888	2.000
35 W	0.74	1.750
40 W	0.703	1.833

4. DISCUSSION

These results show there is a significant relationship between the power of bipolar electro-surgery used and the spread of superficial tissue penetration. This has important implications for the use of bipolar electro-surgery in clinical practice. Clearly the tissues and structures surrounding the intended site of action, along a surface plane, are at risk of unintentional thermal injury. This correlation is not present when considering depth of tissue penetration in a perpendicular plane to tissue surface. Deep tissue penetration appears to be much reduced compared to superficial tissue penetration: the risk to deeper structures appears to be less significant than adjacent structures. However it is useful to note these results do show a significant correlation between diameter of superficial burn and depth of burn for tissue covered with fascia. Although power setting in isolation may not be sufficient to predict depth of burn; a useful indicator and guide to burn depth is the diameter of superficial burn. This provides a clear and real time indicator to the operating surgeon.

There appears to be a mechanism impeding the penetration of heat through the hepatic tissue, certainly compared to superficial spread. Mammalian tissue is mostly composed of water which has a heat transfer coefficient (the measure of a substance's ability to transfer heat) of 10,000 W/(m^2K), compared to air which has a coefficient of only 10 W/(m^2K). Although organic tissue will have a lower coefficient than that for pure water there will be a significant difference in the heat transfer in air and tissue. This may explain the greater extension of superficial burn. Air will not only act as an insulator, keeping thermal energy within the tissue itself but will effectively reduce the potential pathways for thermal energy run off with a proportionally larger amount of energy concentrating along tissue surfaces. The presence of overlying fascia seems to protect deeper tissue layers from the effects of bipolar electro cautery and certainly this experiment shows a far more uniform and extensive penetration pattern in the tissues without fascial protection. This clearly has implications for surgery, tissues not protected by fascial covering must be considered far more at risk of transmitting the harmful effects of bipolar cautery to adjacent structures. The water content across different human tissues does not differ significantly with a percentage content of water between 74–84%. Epidermis being the only outlier with aquoted 65% water content, although the use of bipolar electro surgery on epidermis would be unusual. For this reason we suspect the penetration values for liver to be widely transferrable to all other human tissues that are likely to be subject to electro surgery.

An interesting anomaly in the results is the peak of tissue penetration at 30 W in fascial covered tissue. This is demonstrated in both planes and runs counter to the expected findings. The authors suspect this is a consequence of a threshold effect being reached at thirty watts with a fairly uniform linear progression below this level. At thirty watts we suspect tissue heating reaches a critical level and causes rapid desiccation of the tissues which in turn reduces the heat transfer coefficient; effectively creating a "fire break" which blocks further conduction of thermal energy. This effect is then overcome as the power and wattage increase further and the thermal energy imparted to the tissues increase. A similar trend can be seen in the depth penetration in tissue without fascial covering. Quite quickly the maximum penetration is achieved (25 W) before a slow but linear decrease in penetration is witnessed. This is of particular note as it is a common belief that lower power bipolar settings will help prevent inadvertent thermal in jury, however this data suggests maximum penetration is achieved within a narrow and quite low power level.

5. LIMITATIONS

Porcine liver was chosen to simulate human tissue due to its close physiology and anatomy. Pigs are widely used in surgical research for this very reason but inherent differences will still be evident. A single tissue type was chosen to demonstrate any relationship apparent in changing the power setting of bipolar electro cautery. Further research could compare different tissue types to see if the relationship changes. This is of course an *ex vivo* study and the *in vivo* effects can only be inferred from these results. To perform such a study on live animal models comes with significant ethical constraints.

It would be interesting to know the effects of mono polar electro surgery and whether a similar relationship exists for this technique and whether different tissues share the same properties.

6. CONCLUSION

Bipolar electro-surgery is one of the most commonly used surgical devices and is used throughout the surgical disciplines. However, in the authors' experience the underlying physics remain poorly understood and its use is guided mainly by personal experience through trial and error. This experiment provides useful data demonstrating the tissue penetration characteristics of bipolar electro-surgery and allows the practicing surgeon to develop an internal schema to guide their safe use of this essential surgical device.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. O'Connor JL, Bloom DA. William T Bovie and electro surgery. Surgery. 1996; 119(4):390-396
2. Kelly HA, Ward GE. Electro surgery. Philadelphia: WB Saunder Co. 1932;1-9.
3. Goldwyn RM. Bovie: The man and the machine. Ann Plast Surg. 1979;2:135-53.
4. Cushing H. Electro surgery as an aid to the removal of intracranial tumours with a preliminary note on a new surgical-current generator by W.T. Bovie. Surg Gynecol Obstet. 1928;47:751-784.
5. Luciano AA, Soderstrom RM, Martin DC. Essential principles of electro surgery in operative laparoscopy. J Am Assoc Gynecol Laparoscopists. 1994;1:189-195.
6. Roth K. NMR Tomography and spectroscopy in medicine. Springer. 1984;74.
   ISBN: 978-3-642-69741-8
7. Maddox M, Pareek G, Al-Ekish S, Thavaseelan S, Mehta A, Mangray s, Haleblian. Histopathological changes after bipolar resection of the prostate: Depth of penetration of bipolar thermal injury. J. Endourol. 2012;26(10):1367-1371.
8. Riegel T, Tirakotai W, Mennel HD, Hellwig D, Sure U, Bertalanffy H, Celik I. Comparative experimental study of argon plasma and bipolar coagulation techniques. Acta Neurochirurgica. 2006; 148(7):757-762.
9. Applewhite MK, White MG, James BC, Abdulrasool L, Kaplan EL, Angelos P, Grogan RH. Ultrasonic, bipolar and integrated energy devices: Comparing heat spread in collateral tissues. J. Surg. Res. 2017;207(1):249-254.
10. Jazrawi LN, Chen A, Stein D, Heywood CS, Bernstein A, Steiner G, Rokito A. The efficacy of radiofrequency bipolar thermal energy on human meniscal tissue. Bull. Hosp. Jt. Dis. 2003;61(3-4):114-117.
11. Shellock FG, Shields CL. Temperature changes associated with radiofrequency energy induced heating of bovine capsular tissue: Evaluation of bipolar radiofrequency electrodes. Arthroscopy. 2000;16(4):348-358.
12. Lu Y, Edwards RB, Nho S, Heiner JP, Cole BJ, Markel MD. Thermal chondroplasty with bipolar and monopolar radiofrequency energy: Effects of treatment time on chondrocyte death and surface contouring. Arthroscopy. 2002;18(7):779-788.

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