USING REAL-LIFE CASES TO TEACH STUDENTS ABOUT ELECTRIC BURNS
Part I Contact Burns

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ABSTRACT

We consider the topic of the burning of human flesh caused by electricity. We consider electrothermal burns in this paper and non-contact and arcing burns in the second paper. We teach students that contrary to popular thought, external burning can be good (or at least the lesser evil), since it signifies a resistance to possible damage to internal organs, especially the heart. We further study the effects of contact area and time of application on the skin of the human involved in a medical or health-related situation. Finally, we focus on “good” burning of the human flesh, i.e. we discuss the ubiquitous presence of Electro-surgery machines in the modern hospital operating room.

INTRODUCTION

Generally, one thinks of the dangers of electricity in terms of electrocution or shock. These are good topics to teach students, and we recommend several sources for this [1, 2, 3, and 4]. But in addition to these topics, our students are taught the principles of electricity as it relates to burning. See also [1 to 4]. The purpose of this first paper is to focus on the burning of human flesh created by the application of an electric current, i.e. electrothermal burns. Our second paper will focus on electric burning as a secondary effect; but even as a secondary effect, it can be shown to kill or maim persons and things.

For direct contact of electricity to the skin, experiments have been conducted on the skin of a pig, which has been found to very closely simulate human skin [1, 2]. Let us first define the burn factor (*BF*) as

$$BF = t \times \left(\frac{I}{A} \right)^2 \qquad (1)$$

I is the current (amp), and A is the contact area (cm^2) between the electric circuit and the skin, and t is the time of application (seconds). It should be noted that there is one other factor that applies in this case. What is the conductivity of the skin? If we consider a case of the application of the same electric current to two different people with all conditions expressed in (1) the same, there should be the same degree of burning. However, if one of the persons has a conductive film over the skin in the area of the contact, that person will suffer far less burning. This is the reason why a film of conducting cream is spread over a patient in a hospital setting when electricity is applied. The conductance of the cream enables the burning to be reduced as the effective resistivity of the skin is reduced. We can think of this as an I^2R-heating effect, with the R (skin resistance) reduced. But the hospital must provide a way to limit the current flow in order to reduce the chance of electrocution. We will discuss this again in Case # 1.

We will spend the rest of this paper discussing four real-life cases of electric burning. Let us first clarify some things. (i) Electrocution is an electric shock that leads to death. Without a death, you merely have a shock. (ii) Electricity in (1) is RMS current. Even if the current is a transient, we must determine its RMS value over the time (t) of the transient phenomenon. (iii) Experimental data [1] shows that if the *BF* is less than 0.6, you produce a first degree burn. If the *BF* is greater than 1.6, you can produce a third degree burn. Otherwise, you get a second degree burn. (iv) The rule expressed in (iii) changes if the exposed area is made conductive to the point where a high BF can produce a very mild burn.

ANALYSIS OF FOUR REAL-LIFE CASES

Case I - A little girl is playing with her friends near a water pipe which is somehow charged to line voltage.

The first thing, we need to understand is the contradiction between the burning of human skin and the destruction of internal organs. These effects are generally opposite in their outcome. Consider the case of a little girl playing with her friends [5]. She is apart from them in the front yard of her house. The water pipe leading in to the house should be grounded, but it is not. A live wire has contacted the pipe somewhere. It is at 120 volts. The girl brushes casually across the pipe, and she is shocked. The effect is trivial. But it leaves a small burn. Specifically, there is a gentle redness of skin coloration that indicates a first degree burn and a mild one at that. She runs off to find her friends. She returns with them. She now grabs the pipe with her whole hand. Her skin is moist by now, from sweating. Furthermore, the skin contact area is greatly increased. There is no noticeable burning in this second case. Equation (1) indicates that the electricity is spread over a greater area, and hence the *BF* is greatly reduced. Also, the addition of sweat makes the skin conductive, thus reducing the I^2R heating effect.

The tragedy is that with a reduction in skin resistance, there is a greater flow of electricity in to the girl's body and from her body into the lawn (earth ground) upon which she is standing. She dies in convulsions within seconds.

The lesson learned here is that the burning of skin in the case of electric shock does not indicate the lethal nature of the accident under investigation. In fact, a good rule for this would be that more burning observed in the skin would indicate the skin's ability to impede the electric current and protect the heart, lungs and internal organs.

Hospitals understand this rule. When contact is made to a patient to run electricity through him/her, the contact electrodes are large and conductive paste is applied at the contact area. This guarantees minimal burning. But furthermore, the medical machine must be current limited. Reducing the effects of skin resistance makes the patient more susceptible to electric shock and electrocution. To put this simpler, a patient with a poor electric contact applied to his skin will burn. But the contact resistance impedes current flow, and this protects his internal organs. The patient with a properly affixed contact will not burn, but he can draw significantly more current; this does not happen due to current limiting circuitry within the medical machine.

Case II - A woman goes to a health spa for an electric massage.

When one thinks of a health spa, one assumes that some human will be there to give you a massage by laying hands on you. To reduce the need for manpower and to cater to the greater number of less wealthy clients who would not normally be able to afford a spa treatment, many spas in Europe and America are turning to machines [6]. In addition to spas, chiropractic schools are using machines that deliver electric pulses to produce a deep massage. The principle is this. For low levels of electricity (5 mA to 15 mA [1 to 4, 7]), muscles lock up. They are unable to move. They become artificially tense. Interrupting the electricity will relax the muscles. The only problem with these levels of electricity on internal organs is the possibility of having the lung muscles lock up. The person can become asphyxiated since his muscles are not able to force the lungs to breathe in a normal fashion [7]. Care is taken to place a return electrode in the vicinity of the delivery electrode. So, if a current is applied to the stomach area via an electrode, an adjacent electrode collects the current and routes it to ground. Otherwise, the current could leak to an area near the lungs and leak out of patient by some other route to ground. Furthermore, to dissuade leakage to accidental ground sites, an isolation transformer is used; in this fashion current of the secondary of the transformer does not normally leak to an earth ground site, since it has no way to complete the circuit. By contrast, current on the primary of the transformer would flow naturally to an earth grounding site.

Figure 1: Woman burned on her stomach at health spa, after electrode becomes partially un-glued.

The bottom line is this: there is little worry about the safety of these massage-machines insofar as a person being shocked or electrocuted. They are manufactured to very high tolerances by skilled Engineers. The problem is in the less qualified staff at a health spa in using these machines. This brings us to the question of the burning of the skin.

Application of the pads must be over a fatty layer of skin. Laying an electrode over a boney prominence (i.e. bone covered by an extremely thin layer of skin) or over a well developed muscle devoid of fat increases the chance of the electrode failing to make intimate contact with the skin. This leads to the strong possibility of burning, since the contact area is greatly reduced [1, 8].

Another problem that plagues these machines is the “stickiness” of the electrodes. In a hospital setting (or even in a chiropractic school), there is a serious effort normally to follow proper protocols which dictate that conductive cream be applied to electrode contacts. In the setting of a health spa, the personnel are far less trained. They rely on disposable electrodes which have a sticky surface similar to scotch tape. If the contact is intimate, there is no problem. But if the adhesive portion of the electrode is applied in a fashion that is haphazard or in a fashion that does not make use of the natural straight and curved portion of the body, then the contact is poor.

In one case, a lady in NY city was under treatment for 10 minutes. She was a European immigrant who spoke very little English and who viewed the spa staff as something akin to doctors – they were to be obeyed, since any pain they imparted was for the good of the patient. There were 8 pairs of electrodes applied to her body. Electrodes are placed adjacent to each other; in this fashion, electricity is injected at one electrode and returns by its partner-electrode, so that there is almost no leakage current to cause shock or electrocution. The electrodes were not applied properly. With normal breathing effects, several became partially un-stuck from the person. Had the electrode become completely OPEN, this would have been a good thing since the machine would have sensed the circuit as being open. With the electrode partially off, the current remained constant, but it was distributed over a smaller area (only about 25% of the maximum). This meant (using (1)) that the effective burn was 16 times greater than anticipated. See Figure 1.

The lesson here is that the effect of a burn is reduced when electricity spreads over a greater area.

Case 3 - A woman undergoes surgery-unconscious for 10 hours.

This next case is interesting in that a severe burn was produced by an ordinary 9 volt transistor battery, which one could buy at any store. A woman undergoes surgery. The operation is long (10 hours). Recovery from the anesthesia is long also. The total time that the woman is unconscious is approximately 10 hours. She is hooked up to a host of machines that monitor her breathing and heart rate and oxygen/carbon-dioxide levels, etc. She has a small alarm taped to one of her arms (i.e. the one not tied to any of the other machines). The alarm is powered by a 9 volt battery. Current is very small; current leakage to her skin averages 1 mA. Contact area is about 1/5 square centimeter. Using (1), the *BF* is found to be 0.9. The small current is offset by the large time (36,000 seconds). Her burn is second degree. There is both surface skin damage and deep skin damage. However, she is spared the charcoaling of the skin that is indicative of a 3^{rd} degree burn. Extra care should have been taken to put an insulating pad between the alarm and her skin before the alarm was taped to her body. The pad would have thwarted the flow of electricity which would have prevented burning.

Case 4 - Electro-surgery

Up to this point, we have discussed electric burning as a negative thing, i.e. something we should avoid if at all possible. But consider that fully 80% of the people in America that undergo surgery do so via electro-surgery. It is interesting and somehow entertaining to watch a TV show where a surgeon picks up a scalpel and prepares to make an incision in to the patient's skin. But this only happens in approximately 20% of the medical surgeries that take place. Instead, electricity (and not a scalpel) is used to cut skin or to cauterize exposed blood vessels. You can think of this as a controlled burning of the skin. Done properly, this is a very good thing. Done improperly, the patient's body can catch fire. [See for example 1 to 4 and 8]. See Figure 2 also.

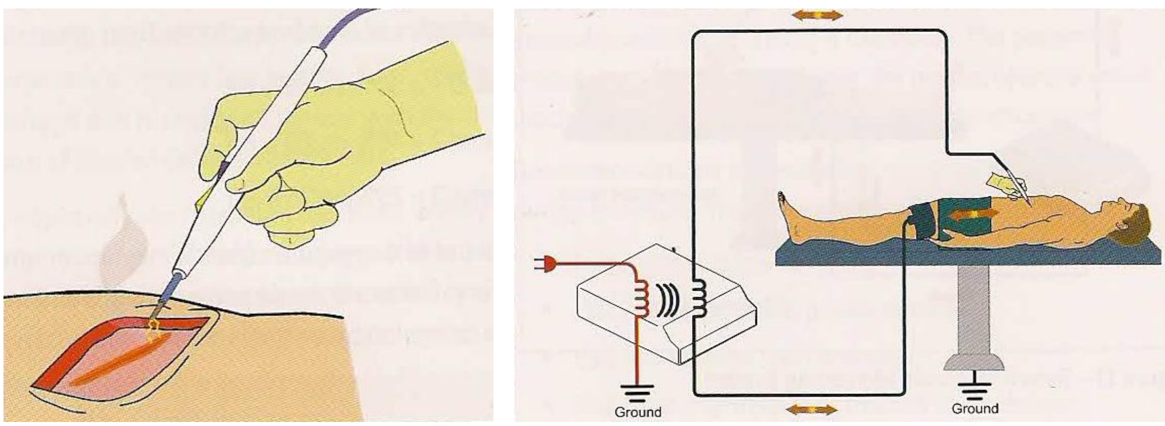

Figure 2: Electrosurgery picture shows the path of electricity and the application of the "electric scalpel" or "pen" used by the surgeon.

CONCLUSION

We analyzed the burn factor and the skin conductivity in the production of burning in a human, due to contact with electricity. We found that a larger area decreased the incidence of burns, but it could increase the risk of injury to internal organs. Where current was controlled, more contact area made burning less likely and less intense. Furthermore, the time of application was found to be a key factor in electric burning, where the human was incapacitated for many hours. We also noted the benefits of electric burning, via electric surgery.

These are important topics to teach Engineering students, and especially Biomedical Engineering students. Not only do they explain basic electrical safety, but also they clarify the basic Physics involved in the process of electrical conduction in the human body.

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