

Forensic Analysis of Electrical Injury Using Burn Pattern to Predict the Incident Narrative

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Abstract— Electrical-burn injuries preserve a detailed record of an incident's dynamics through their unique patterns. In this paper, we demonstrate how a systematic analysis of burn morphology—shape, size, location, and tissue characteristics—combined with scene context and human response modeling, can reconstruct the sequence of events in an electrical-injury (EI) case with high precision and probability. Starting with and then moving beyond traditional metrics (voltage, entry/exit points, shock duration, theoretical current pathway and estimated current magnitude), we examine how laws of physics, when applied to the four distinct types of electrical burns (flash, arc entry/exit, resistive and flame), can be used to paint a vivid picture of an electrical incident. We detail the underlying physics of each burn type and present multiple illustrative case studies that translate burn-pattern data into coherent forensic narratives. This methodology not only enhances the accuracy of injury reconstruction but also provides dynamic insight into event evolution, offering a powerful tool for investigators and expert witnesses.

Index Terms — forensic engineering, electrical injury, electric burn pattern, flash burn, flame burn, resistive burn, arc burn.

I. INTRODUCTION

In the electrical safety culture, for every set of facts, there should be only one definitive narrative. Anyone who has watched a trial can tell you that for almost every litigated incident, the jury will be presented with two “definitive” albeit conflicting narratives, each sworn to by highly qualified experts as being “more probable than not.” It is an impossibility for two diametrically opposing narratives to both be probable (more than 50%) at the same time.

Any approach to establishing the true narrative must rely as much as possible on that which can be reliably held to be of such a high probability as to approach irrefutable.

For the purpose of this article, the authors define “irrefutable” as that which is held to be an absolute in most common circumstances. The law of gravity is, by most, seen as irrefutable in that if you drop an object, it falls to the earth. In electrical engineering, Ohm's law is irrefutable if two of the three variables are correctly known. The breakdown of air to initiate an arc is another example of a physical law that approaches irrefutable within known limits. The authors recognize that laws of physics may, in some circumstances become fluid and become refutable

but those situations tend to exist far beyond the realm of the common situations in which electrical contacts occur.

To approach the definitive (irrefutable) narrative, one must look at the reliability of the underlying facts. An unaltered photograph is more reliable than eyewitness testimony (which in high stress situations is known to be notoriously unreliable) [1]. Still, a photograph (not altered by humans or AI) is reliable for what it contains. Anything not in the frame and anything in the time before or after the moment the photograph is taken becomes progressively more speculative. An unaltered video is better than a picture but still no better than the angle, aperture and resolution associated with the image.

The goal of deriving the highest probability narrative, is best served when reliance can be placed on that which approaches irrefutability in the common realm of electrical contacts.

The authors describe how the application of simple but (near) irrefutable rules of physics to burn pattern data can result in the most probable incident narrative. The authors look at (or towards) statements that can be made as absolute facts (approaching 100% probability) without the induced variability of individual speculation. It is not about extensive calculations which are too often based on assumed boundary conditions and refutable assumptions upon which experts will ultimately come to disagree.

The authors take the approach of identifying each burn type and then applying basic rules of physics without making overreaching assumptions that could open the statements to adversarial challenges. Physics, when applied properly (and narrowly) to burn types, can become the best witness to electrical incidents.

II. ELECTRICAL INJURY BURN TYPES

There are four burn types (resistive, arc entry/exit, flash and flame) generally associated with electrical incidents [2, 3, 4,5]. Common among all burns is that sufficient energy must be imparted to the tissue to alter its structure to create the damage identifiable as a burn [6]. Each burn type is defined by the physics that describe how the energy is imparted into the tissues. Clinically, high-voltage (HV) injuries, being commonly defined as contacts with greater than 1000 volts, are associated with more extensive Total Body Surface Area (TBSA) involvement, longer hospital stays, more complications, and higher amputation rates than low-voltage (LV) injuries, being commonly defined as less than 1000 volt contacts, (n=376; HV amputations 37.3% vs LV

22.0%) [10]. High voltage or low voltage, each burn, taken in context, becomes part of the narrative. The physics associated with each burn type acts to establish hard boundaries in the narrative. It all starts with the specific expertise necessary to identify each burn type. (Table 1 compares the four burn types.)

The four burn types are as follows:

A. Resistive Burns

Resistive burns (which are also broadly and commonly referred to as I^2R or joule burns) can occur in both low and high voltage contacts. The energy imparted in joules is given by:

$$E = VIt$$

Or

$$E = I^2Rt$$

Where E , V , I , t , R are energy, voltage, current, time, and resistance, respectively.

$$E(\text{calories}) = E(\text{joules})/4.184$$

Resistive burns are caused by resistive heating of tissue due to current flow through the tissue against the local resistance of the tissue. The amount of heating is proportional to the voltage drop across the tissue, the time of contact, and the current (density) through the tissue. Clinical reports corroborate that deep tissue damage scales with $I^2R \cdot t$ and becomes limb-threatening in high-voltage contacts [9]. For human tissue, even a superficial burn (commonly called a 1st degree burn) requires raising the tissue to 50C for 20 seconds which for a 1 cm³ sample would require imparting 26 joules into the tissue [6].

Simple physics tells us that at household voltage levels (120 volts), resistive burning takes significant time (mediated by current density and local resistance.) The presence of a burn from a household shock says that the shock was prolonged beyond a mere momentary contact.

At power line levels, energy is imparted into the tissues at a very high rate (compared to household voltage). Resistive burning occurs almost instantaneously and can rapidly become full thickness with charring (typically called 3rd or 4th degree burns). For a power line contact, limited resistive burning can be predictive of incident brevity.

Resistive burns on the surface (called contact burns) tend to follow the shape of the contact. Resistive heating below the tissue surface can project thermal damage deep into the tissues along the pathway of the current flow. Deep resistive burning indicates shock duration and often predicts the entry point based on the higher current density associated with a single-entry point when there are multiple current exit points.

Amputations are most often the result of deep resistive heating causing tissue necrosis, tissue swelling, and resultant compartment syndrome. High-voltage electrical injury (EI) commonly precipitates compartment syndrome; timely fasciotomy and staged reconstruction may salvage the limb [9]. A 10-year series reported major amputations in 25.8% of HV cases vs 5.0% of LV, underscoring the limb-threatening nature of deep resistive injury in HV contacts [10]. Resistive burns are most prevalent at or proximate to contact points where current enters or exits the body and where local current density is highest.

As all tissues are resistive, resistive heating will occur in all

tissues that current passes through but if the current density is too low or the duration is too short, burning and tissue damage cannot occur.

Resistive burns at the surface are identifiable by a distinctive appearance that ranges from quickly resolving reddening (first degree) to skin necrosis with blistering (second degree) and sloughing to full thickness burns with charring (3rd or 4th degree). Resistive burns from low voltage contacts are easier to identify than those from higher voltages which often have associated arc entry/exit components.

Resistive burns can be used to give definitive information about contact points, and to give relative information about shock duration (particularly in low voltage contacts).

The most extensive resistive heating will occur where the current density is highest and can often predict the current entry point.

B. Arc Entry/Exit Burns

These are burns where current enters or exits the body via an electric arc. The physics of arc initiation requires that there exists an air gap less than the distance as defined by the dielectric breakdown of air. For air to break down and ionize into an arc requires approximately 30,000 volts for each centimeter of air gap [5]. (As an example, if the source voltage is 7500 volts, to initiate an arc would require an air gap of approximately no more than ¼ of a centimeter because 7500 volts/30000 volts per centimeter = .25 centimeters.) Although the breakdown of air is known to vary with environmental conditions, high probability predictions of maximal source proximity can still be easily made in most circumstances.

Arc entry/exit burns tend to be very distinctive and relatively easy to identify. They most often appear as highly carbonized (black) in the center due to the intense heat of an electric arc which can be as high as 35000 degrees [5]. Arc entry/exit burns tend to be circular and surrounded by healthy unburned tissue beyond the margins. The full thickness (3rd degree) portion of the arc entry/exit burn may be relatively small with a more obvious partial thickness surrounding burn.

Even small arc entry/exit burns can be indicative of a high voltage, high current contact. Given the near instantaneous tissue carbonization, they are not necessarily indicative of contact duration.

A common mistake made in emergency rooms is to assume that small diameter arc entry/exit burns (which can be less than a centimeter across) are indicative of a brief shock or of little internal injury. Nothing could be further from the truth.

Arc entry/exit burns are absolute indicators of proximity to either the current entry point or exit point on the body as bounded by the dielectric of air. Arc burning can often be used with high accuracy to predict body position at incident initiation.

C. Flash Burns

These are burns that tend to cover large surface areas. They are surface burns caused by proximity exposure to the radiant and convective energy of an arc flash. They are absolute indicators that the victim was proximate to the arc flash [7, 8]. In a brief incident, flash burns can be very minor first degree (skin reddening) but can range to second or third degree (partial thickness to full thickness). The farther from the heat source, the less significant the burn. Longer incidents can cause much

TABLE I
ELECTRICAL BURN TYPES AND THEIR FORENSIC IMPLICATIONS

Burn Type	Voltage	Appearance	Burn Depth	Predicts
Resistive Burn	Both HV & LV	Sunburn to blistering and charring; often matches the shape of the contact.	Surface (contact burn) to deep resistive heating.	Entry point and shape of contact; for LV, often predicts duration.
Arc Entry/Exit Burn	Almost exclusively HV	Black, carbonized center with a surrounding margin of damaged tissue and healthy tissue beyond.	Surface burn with possible deeper resistive heating.	Proximity (with high probability) to source or ground; can predict body position or a grabbing action.
Flash Burn	Almost exclusively HV	Uniform pattern diminishing with distance from the arc source; ranges from sunburn-like erythema to surface charring.	Surface only.	Proximity to the arc; can predict orientation relative to nearby structures.
Flame Burn	Almost exclusively HV	Typically significant and matches the area of burnt clothing.	Surface only.	Often masks other burn types and reduces their predictive value.

deeper flash burns. Flash burns proximate to an arc will occur almost instantly. Flash burns are most identifiable by their uniform appearance and diminution as distance from the arc increases.

Flash burns are not indicative of current entry into the body. Flash burns can be used as indicative of proximity to the source as well as indicative of body orientation.

D. Flame Burns

These are caused by the ignition of clothing, usually from the heat of a proximate arc flash. They are not an indication that there was an electric shock. These are surface burns and take the longest amount of time to develop as the temperature of the flame is far less than the temperature of an electric arc. Flame burns are often obvious from burnt clothing. (This is differentiated from arc flash burning which can occur through the clothing and arc entry/exit burning which will typically ignite the clothing at the point of the arc. Flame burns tend to track with large areas of burnt clothing.

Flame burning has the unfortunate consequence of masking other burn types and reducing the accuracy of burn interpretation.

III. PROCEDURE TO USE BURN PATTERN

To effectively use the burn pattern to establish a higher probability narrative requires limiting the formation of opinions to those that are defined by the irrefutability of physics, all taken in context with what else is known of the incident. Most important is to stick to statements that can be made with extremely high probability and to avoid speculation and overreach. This includes the following:

1. Initiation of an arc is controlled by air breakdown (30KV/cm) such that the presence of an arc entry/exit burn defines the distance limit from the current entry or exit point when the arc was initiated.
2. Arc flash burns being a function of proximity to an arc indicate presence in the field of an electric arc and thus tell a story of proximity. The pattern of the burns often

indicates body positioning (greatest intensity burn being closest to the arc.)

3. Shadowing of flash burns often indicates body positioning proximate to objects in the environment.
4. Contact resistive burns delineate the shape of the energized contact. Contact burns require a current density such that no burn will occur where there was no current flow (exclusive of proximate burning in long duration contacts).
5. Position of contact burns on the palmer surface of a hand indicates a grabbing motion while burns on the back of the hand indicate a brushing/glancing contact.
6. For household voltage shocks, the presence of burns suggests a non-instantaneous shock and when taken in conjunction with location (such as the palm of the hand) can indicate that there was a no-let-go contact.
7. Deep tissue burning, being resistive, is a function of current density, local resistance, and time. Such burning taken in the context of other burn locations can define the entry point where the current density had to have been the greatest.
8. The lack of burns can provide powerful evidence that parts of the body were not involved or were not proximate to the source or exit points.

Each burn tells its own story, and each must be taken in context. The information is often limited but it is part of the overall narrative. The desire to overreach and to find more than that which is truly there (informational) will only serve to hinder the validity of the final narrative. The process is as follows:

1. Locate the earliest pre-treatment photos available. (Police photos at the scene, autopsy photographs, day of incident emergency room photos or burn center pre-treatment photos.) Burn pattern information is lost as soon as treatment begins.
2. Learn as much about the incident as possible by reviewing all witness statements, first responder reports, police reports, OSHA investigation (where available), and scene photographs.
3. Establish (through discovery) known hard parameters such as contact voltage, fault data, breaker trips, or recloser operations.

4. Review medical records to establish as much as may be known about the incident, the burn locations, the degree of burning, and existing narratives (HPI) communicated to medical providers. Review labs (specifically Creatine Kinase-- CK) for indicators of deep tissue injury.
5. Establish a working (preliminary) incident parameterization. Use all available information to establish predicted baselines for source voltage, incident duration, most probable entry and exit points and current pathway in the context of the known physical environment.
6. Review all burn photographs and categorize each burn area by type. Do not overreach. Not every burn can be characterized. Consider if one type of burn may be masking another type. (Example: A flame burn can easily mask a flash burn or a contact burn.) Consider that some burns may represent two or more burn types. Consider that not all burns will occur at the same time during the incident.
7. Let physics set boundaries on the narrative of the incident. (A common example is where a victim will say that they were not close to the source, and that electricity "jumped" out several feet to reach them. Given the source voltage, and even allowing for realistic variability in air breakdown, it is easy to establish the greatest possible distance that they could have been from the contact point with near 100% probability.)
8. Use burn pattern and burn type in context with the physical environment to establish what burns were entry points and what burns were exit points.
9. Consider that a lack of burning is also informational. A lack of burning can predict shock brevity.
10. Look for discontinuities between physics and the burn pattern. Individuals will often report marks on their body after an incident and identify those marks as burns. As an example, in household voltage contacts, you will almost never find burns where there was no physical contact with either the source or the exit point to ground. Skin in contact with air will not manifest a burn.
11. In the context of the boundaries established by physics revise the final incident narrative such that it reconciles all available data about the incident with the physics presented by the burn pattern. Where an eyewitness (or other data point) conflicts with boundaries established by physics, the laws of physics (being near absolute) must set the boundaries of the narrative.

IV. EXAMPLES WHERE PHYSICS COUPLED WITH BURN PATTERN WERE USED TO ESTABLISH A DEFINITIVE NARRATIVE

A) Scenario 1

A body is found on the ground near a swinging live power line (7kV) that repeatedly hit one of the decedent's feet. The event was unwitnessed. The burn pattern was highly complex, but most burns were consistent with injury after the decedent fell to the ground. Most burns were matched to burning on the ground under the decedent or to the swinging power line. One burn however could not be explained. The decedent had his hand in his sweatshirt pocket. An obvious arc burn was found on his

hand with a matching burn through the sweatshirt. There were no markings on the ground proximate to the hand and his hand in the sweatshirt was several inches above the ground.

Conclusion: Understanding that for arcing to occur from his hand to ground (after he came to rest on his back), his hand (through the sweatshirt) would have had to have been almost in direct contact with the ground because the dielectric of air mandated proximity (< .25 cm) to the earth in order to initiate an arc to ground. In the context of the environment and the full burn pattern, the only explanation was that the burn to the hand occurred while the decedent was still standing. Either the power line fell and brushed by his hand (close enough to initiate an arc) through the sweatshirt or the power line swung and brushed by his hand (close enough to initiate an arc). In either case, the more probable narrative was that the burn to his hand was an entry wound and the initiating contact that brought the decedent to the ground.

B) Scenario 2

In an unwitnessed event an individual is found with an arc burn on the side of one foot. He has a matching burn on his sock and an obvious but very small burn through his work shoe right above the sole matching the location of the arc burn to the foot and sock. He had burns on his hand that were contextually obvious as entrance burns. His body position at the time of contact was called into question.

Conclusion: The placement of the burn on the shoe (consistent with the dielectric of air and the much higher dielectric of the rubber sole) is an absolute indication that an arc was drawn from the side of his foot right above the sole of the shoe to ground. This is an absolute indication that he was standing when the arc burn occurred.

C) Scenario 3

An individual claims a shock from a 120-volt outlet. Their narrative is that the shock, which they described as brief, occurred while pushing the plug in. Under oath they testify that their other hand was in contact with nothing but air. They identified multiple burns on their body and claimed that their fingernail was charred and that a ring that they were wearing was physically (not thermally) damaged.

Conclusion: Physics proves an incredible witness in this case. The victim initially describes a shock with same hand entry and exit points which precludes contact burns remote from the hand. Contact burns can only occur where there is resistive heating involving both current flow and time. The issue of burning to the fingernail is also precluded by physics in that the fingernail even if energized for the duration of a brief shock is more of an insulator such that the current flow would approach zero yielding almost zero energy imparted into the nail. No energy yields no burning. The issue of an arc burn to the nail was considered but arc burning at this voltage is extremely unlikely and an arc would not likely have been

drawn when plugging into the outlet. Finally, there is no known force in physics that could have explained bending a gold ring in proximity to this low voltage shock. Although a shock was not fully precluded, the reliability of the victim narrative was called into very serious question.

V. CONCLUSIONS

Careful application of laws of physics can be used to establish irrefutable boundaries when applied to burn pattern information. All taken in context burn pattern information can be used to establish the most probable narrative for an electrical contact or proximity scenario. Similarly, the validity of narratives of victims, witnesses, and experts can be tested and supported or refuted in the context of the physics of an electrical environment. Physics can serve as the most accurate witness to an electrical incident.

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VII. VITA

Michael Morse is a professor of electrical engineering at the University of San Diego. He has been conducting forensic investigations of electrical incidents for almost four decades, during which time he has consulted in over 600 electrical injury cases. In many of those cases, he has applied irrefutable laws of physics to develop the most probable narrative. Throughout his career Dr. Morse has studied and researched the effects of electricity on the human body and associated symptomatology consistent with the parameters of the shock received. This has led to a body of published statistically valid studies during which Dr. Morse has explored the less known and more dramatic impacts of seemingly minor electrical contacts. Dr. Morse has also published numerous accounts of his forensic investigations. As a forensic expert, he has testified in electrical injury cases over 200 times. He has also become an expert in using electrical injury burn pattern to develop the highest probability narrative of an electrical contact. Dr. Morse received his B.S. and M.S. in Biomedical Engineering from Tulane University in New Orleans in 1981 and 1982. He went on to get his Ph.D. from Clemson University in South Carolina in 1985. He concluded his academic studies with a law degree from the University of San Diego in 1999. Professor Morse joined the Electrical Engineering Faculty of Auburn University in 1987. At Auburn he published on the topics of speech recognition from signals secondary to speech and electrical stimulation. In 1990, Dr. Morse joined the faculty of electrical engineering at the University of San Diego. Professor Morse has throughout his career been active in teaching, research, and consulting. His research has included studying symptomatology of electrical injury, pathways followed by current during an electrical accident, and analyzing the potential for injuries such as Carpal Tunnel Syndrome. Professor Morse teaches forensic engineering, biomedical engineering and engineering law among other classes.

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Venkat Shastri, PhD, currently serves as the De Sanctis Professor of Engineering and Entrepreneurship at the Shiley-Marcos School of Engineering. In Spring 2022, he began his role as the Chair of the Electrical Engineering department. Between

2020 – 2022, he also served as the Founding Associate Dean of Graduate Programs in the school. In 2020, he co-founded, and led as CEO until June 2024, a diagnostic company called ALZpath, Inc., focused on early detection of neurological disorders. Prior to joining USD in 2014, he served as the Chief Industry Advisor of PCN Technology, Inc., to strengthen the company's strategic positioning in the market. In the preceding eight years, as President and CEO, he grew PCN into a market leader in communication, industrial networking and energy management solutions. Between 2002 and 2004, Venkat was VP of Engineering at Palomar Technologies, a packaging equipment and process solutions company serving the semiconductor, telecom and medical industry. At Palomar, he led engineering and was responsible for all product releases and product roadmaps. Before this, he was Senior Director of Engineering and Product Development at KLA-Tencor, where he managed its automation products and solutions, and was a key customer interface to Intel. From 1988 - 2000, at JPL and then at SRI International, Dr. Shastri conducted research in robotic manipulation, legged locomotion, adaptive control and nonlinear systems. He grew the latter into a center of excellence in bio-

automation. At JPL, he worked in the Space Telerobotics, Mars Pathfinder and Sample Return programs. Dr. Shastri received his PhD in Electrical and Computer Engineering from the University of Massachusetts in 1988. He is the author of a book entitled, "Dexterous Robot Hands," (Springer-Verlag, 1990), and has published over 30 scientific articles in journals, magazines and conferences. He was Research Scientist at Yale University (1994 – 1996) and Consulting Professor at Stanford University (1998 – 2000). He has served on the Editorial Boards of IEEE Computer Society and IEEE Control Society, and led the publication of two special issues, in the IEEE Robotics and Automation Transactions and International Journal of Robotics Research. He holds patents in controls, robotics, Bio-MEMS and electro-active polymers, and has served as principal or co-principal investigator on large multi-center research grants and contracts. Dr. Shastri was awarded The Engineering Leadership award by the San Diego County Engineering Council in 2019. In 2024, he was selected as a TIME 100 in Health honoree.