Stray Voltage (SV) Injuries in Dairy Farmers: A Review of Five Cases

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Abstract: Stray voltage (SV) injuries have been documented in the United States since 1969. SV injuries are a common occurrence on all types of farms including dairy farms. Recently, there has been an increase in reported cases of SV on city streets and city sidewalks. The effects of SV can cause serious injuries and even death among humans and animals.

From 1999-2002, five patients were seen and treated at our clinic due to neurological complications from stray voltage (SV) injuries. Among all the neurological complications associated with SV, one patient developed complex regional pain syndrome (CRPS). All five patients were dairy farmers. Each patient developed severe neurological problems. It took years before these patients were diagnosed with SV injuries. Their livestock also suffered injuries and even death from the SV on the farms. In this article, we will discuss how SV can cause permanent damage.

Keywords: electrical injury (EI), stray voltage (SV), dairy farmer's (DF), complex regional pain syndrome (CRPS), infrared thermal imaging (ITI).

INTRODUCTION

The exposure to electrical injuries (EI) does not cause the homogenous and uniform electrical contamination. The following factors play a major role in the development of EI.

The first factor: Low resistance of the skin, In the Ohm's Law, V = R x I (voltage = resistance x intensity of the electricity). In this formula, for a set amount of voltage of electricity the lower the skin resistance, the higher the amount of amp intensity or amperage of the amount of electricity that enters the body.

The second factor: The amount of electricity and its intensity (I) which is measured by the ampere unit. As the low skin resistance opens the gate for more electricity to enter the body, even a small amount of current (amperes), causes potentially fatal damage.

The third factor: As the Ohm Law shows, voltage is not as important because if the skin is dry, then far less electricity enters the body, and the less the amount of electricity entering the body, the less the electrical potential for voltage is going to be.

As the electricity enters into the body, it follows the path of least resistance which are interior blood vessels and sympathetic nerves surrounding the blood vessels. The electricity follows blood circulation up to the heart and follows the sympathetic nerve fibers in the same path. From there the electricity enters the spinal cord at the thoracic spinal cord level causing the thoracic spine dysfunction.

HISTORY OF STRAY VOLTAGE (SV)

Stray voltage (SV) has been documented for decades worldwide. As early as 1948, the first documented case of SV in Australia was reported by Churchwood (2). He reported that current resulting from electrical equipment in the milking area may have affected the cows during the milking process.

In 1962, Phillips from New Zealand also reported similar findings by Churchwood 14-years earlier in 1948 (3,4). In 1969, the first reported case of SV in the United States was reported in Washington State by Craine, et al. (5). In 1975, Feistman and White from Canada also reported cases of SV (6). By the mid to late 1970s and into the early 1980s, SV cases were reported throughout parts of the United States and Canada (7,8).

By 1982, there were many published articles regarding SV in dairy farmer's magazines to help spread awareness of this very complicated and serious issue that dairy farmers and their cattle must deal with.

Over the years, since the first documented reported case of SV, there have been numerous articles and books written on the subject of SV.

CASE REPORTS

CASE #1:

The patient is a 32-years old male and a dairy farmer (DF). He was exposed to 4-60 volts of electric exposure to electrical current for 22-days while working at a dairy farm, milking cows. The power and light electricians recorded the electric charges of stray voltage (SV) in the ground, barn, and metal building. The barn was only 30-feet away from the transformer. The 60-volt charge was in the sink of the farm.

The buildings were all-metal, with much water all around. Every time he touched anything in the barn, he received a shock. He did this twice a day every day for 22-days. He experienced electric shock feeling in his extremities, he also developed hypertension, server headaches, tremors of the extremities, fatigue, attacks of pallor, as well as becoming irritable and short-fused. He complained of having no patience, and no ambition.

CHIEF COMPLAINTS:

The patient complained of pain in his hands that is rated at an eight based on a scale of 0-10. He has severe pain in the joints, especially the knees and feet. He has left knee and foot pain. His pain gets worse with long hours of work and on rainy and cloudy days. He reports that his head feels like it is in a vice and the pain never goes away.

Other complaints:

- Dizziness, and poor balance.
- Severe headaches.
- Neck pain, and low back pain.
- Poor sleep. He is irritable, edgy, and short-fused, and has fluctuations of appetite.

REVIEW OF SYSTEMS:

A review of the neurologic examinations done on this patient before coming to our clinic reveals a tendency for gradual deterioration which is not exactly so slow and has become more obvious in the past year.

According to the patient's medical records, he has developed problems not only with the intracranial mass, but also there is evidence of posterior fossa involvement in the region of the cerebella and the brainstem connections. This has been manifested by positive Romberg, and typical ataxia.

More importantly, the medical and neurological reports emphasize the presence of both the central nervous system and peripheral nervous system sensory loss. This is quite significant because it strongly suggests that the patient's hand may have been the conductant, and exposing the peripheral and central nervous system to the electric charge because of voltage leakage.

The patient has blotching of both lower extremities from the waist down with spots of purplish color alternating with pale color. This is the classic picture of neurovascular instability secondary to a dysfunctional sympathetic system.

The patient has very wet hands. He exhibits sweaty palm of both hands, more on the left. He also has marked erythematous discoloration of the hands with blotching, pointing to sympathetic dysfunction.

The patient has neuro-inflammation, maximal in the hands with swelling of the fingers. The sympathetic nervous system changes mentioned above and asymmetrical sweating of the hands are all classical pictures of sympathetic nervous system failure.

The patient also had dystrophic changes of the toes, more on the left side. These are in the area of the dorsum of the feet and in between the toes.

The patient has classic thermatomal distribution sensory loss from the fingers up to 2-inches below the elbow. This is typical of sensory loss seen in sympathetic dysfunction.

He has a similar sensory loss in the lower extremities from the toes up to 3-inches below the knees, again typical of sympathetic dysfunction.

The patient had marked occipital nerve irritation on the right side. This was treated with an occipital nerve block with 3cc Marcaine and 2.5mg Depo-Medrol ®.

In the cervical spine region, he had paravertebral nerve irritation over the left C1-C2 level. A paravertebral nerve block was done at this level with 3 cc Marcaine and 2.5 mg Depo-Medrol ®.

The areas were selectively identified by asserting equal gentle pressure over the posterior spine regions. The gentle pressure on these areas identified the areas of reddish discoloration of the skin due to injury to the paravertebral/epidural nerves as well as areas of focal paraspinal spasms in the same area. These were treated with paravertebral and epidural nerve blocks.

IMPRESSION:

Repetitive exposure to SV leakage caused by the grounds of the farm and the underground pipes.

It took two years for the lack of grounding to be corrected, but the patient is left with the complications of repetitive exposure. The SV has caused permanent damage to the sympathetic sensory nerves and the sympathetic system especially the spinal cord, as well as the limbic system in the form of bouts of irritability, agitation, depression, and short-fused.

Also, the brainstem and cerebellum have been affected by the EI causing ataxia and wide-based gait as well as damage to the left 8th nerve (hearing nerve).

The EI has already damaged the sensory nerves in the upper extremities which were documented by EMG/NCV studies that were done two years before coming to our clinic.

The repetitive exposure to EI has caused immune system disturbance and high ANA titer with indications suggestive of lupus and also has caused neurodermatitis. This will be treated with Vistaril q4-6h prn.

There are other indisputable proofs regarding electrical leakage in the same environment. The cows have shown a reduction in milk production. Simultaneously, the cows have shown severe anxiety when they are led to enter the barn for milking.

Another quite significant evidence is the fact that the patient has been the only person in that environment who has shown the above mentioned typical EI complications.

The other people in the same environment did not expose their hands in the water sink as the patient has done routinely.

So, the electrical conduction has been more selective to affect the patient rather than the other people being exposed to the same environment.

The fact that the cows were in a humid environment, they were at a higher risk for the conduction of electricity to their bodies. The fact that the patient had to use the sink in the barn and other people did not have to use the same sink, the electricity singled him out by the current being transmitted through the wet skin of his hands.

Additionally, as has been the case with other SV patients that we have seen, the measurement of the water and humidity in the ground has recorded up to 4-volt's electrical charge voltage potential. This is higher than the usual 1-2½-volt electrical charge that is seen in similar environments.

INFRARED THERMAL IMAGING (ITI) FINDINGS:

Because of neuropathic pain, the patient underwent infrared thermal imaging (ITI). ITI shows marked hypothermia in both hands, maximally over the fingers where the temperature is recorded at only 24.5°C in the right fingers and 24.4°C in the left fingers.

Also, he has marked hyperthermia in the palms of both hands in a circular fashion 1 ½ inches wide where the temperature is quite high at 28. 7-29°C. This sign is classically typical of EI. It is referred to as the "sign of the cross". This is a pathognomonic exclusive sign of EI. This points to the right and left hands being exposed to electricity, and the electric current damaging the sympathetic nerves and causing the leakage of body heat through damaged areas. This explains the patient 's problems with neuro-inflammation, joint pain, swelling and inflammation of the fingers, and burning in the hands.

The ITI of the feet shows much more severe hypothermia with the temperature ranging 22.3-22.4°C which is extremely and pathologically cold.

In contrast, the temperature of the forearms is 30°C, and the temperature of the thighs is 31°C.

The posterior cervical region shows marked hyperthermia where the temperature is recorded at 32.75-33°C. This area is showing marked leakage of heat because of the irritative chemicals released by electric current cause severe damage to the sympathetic system, and severe heat leakage in these areas. This also corroborates with the complaints of headache and neck pain.

This ITI is typical of the changes seen in EI.

FINAL IMPRESSION:

This patient has suffered from EI through his extremities, maximally over the hands and knees. This has caused a severe neuropathic sympathetic sensory loss in both bands, which makes it difficult for the patient to distinguish between hot and cold. This also causes pain in the same areas.

The entrance of electricity to the spinal cord has also caused spinal cord dysfunction as documented on the somatosensory evoked response (SSER).

The patient's thermal sensory sympathetic nerves dysfunction of moderately severe degree has - caused total body impairment for the upper extremities. The injury and dysfunction of the spinal cord causing gradual deteriorating.

The pain is secondary to damage to the sympathetic system nerves causing not only pain but also the weakness of the hand and feet.

The neuro-inflammation involving the hands and feet in the form of swelling and clumsiness in the use of the fingers and difficulty with walking.

This case is a stereotypical clinical picture of an EI.

CASE #2

The patient is a 53-year-old male. He is a dairy farmer (DF) and was in normal health until mid-summer of 1989. At that time, he began developing headaches that lasted all day. His headaches continued to get worse over time. His wife (case #3) also had similar symptoms while living on the dairy farm.

CHIEF COMPLAINTS:

He complains of severe ulcerations of the right hand and fingers; ulcers on the left elbow.

Other complaints:

- Headaches.
- Episodes of uncontrollable blood pressure.
- Break-out of skin lesions.
- Chronic renal insufficiency of the left kidney.
- History of numbness and tingling of the face and extremities.
- Ringing in the ears.
- Poor balance.
- Memory loss.

HISTORY:

In mid-summer of 1989, the patient's dairy cattle began developing high cell counts in their milk, and he started to sell them off because he could no longer sell the milk.

In October of 1990, some of his dairy herd began to develop eye problems and large under-the-skin knots around their bodies. Several of the cows even died. With these problems worsening drastically, he sold and traded the dairy herd for beef cattle. However, the beef cattle developed the same types of problems.

After the patient got rid of his dairy cows and all the milking equipment, his electric bill continued going up and became very erratic. He could not understand why this was happening? It should have gone down without the electric milking equipment.

Sometime in 1992, he purchased a large quantity of beef cattle. This new group of cattle began losing weight and their eyes were watering. Some of the cow's eyes would water for two to three days and then burst. The pregnant cows began having problems with perfectly formed calves being stillborn or born prematurely and underdeveloped. The bulls were not interested in breeding. Several of the cows in this herd began to die.

In the fall of 1997, the patient had borrowed a voltage meter because he believed that there was some sort of electrical problems at his farm. He began measuring the voltage on the property and found that there was a large amount of SV on the property.

In January of 1998, he called the local electric company and requested that they come out with a voltage meter to check his property. The electric company found SV coming from the underground pipeline.

When he found out about the voltage, he was told that the ground wire runs down the pipeline to prevent corrosion. The pipeline was 69-years-old. He began to question why his electric bill went up and he was finally told that the SV causes the motors in the electric meters to pull more amps than they are supposed to. It causes the kilowatts to go up. He bought a 5-HP well pump which was supposed to pull 35-amps, but it was pulling 62-amps vs. 35-amps.

He had a veterinarian come out to his farm to check on the health of his cattle. She felt the cattle's problems were caused by the SV on the farm's property, but she did not exactly understand how this was happening.

He has asked other farmers who lived nearby if they had the same problem with SV. They said yes, they were having the same problem with their cattle and with their own health.

REVIEW OF SYSTEMS:

In April of 1997, the patient was treated for an infection that mysteriously developed on his right hand and elbow.

The patient has moderate neurosensory hearing loss over the left ear. Weber is lateralized to the right. BER shows no significant delay.

He has marked nerve irritation in the distribution of the right and left lower cervical nerve roots in the lower cervical regions due to referred pain from the lesions in the upper extremities. He also has moderate sensory loss over the right cervical paraspinal region.

He has a large, deep ulcer, going through all layers of the skin, all the way down to the muscles with extensive granulation, marked erythema surrounding these lesions. The ulcer is multiloculated showing four separate expansions, 3-5 cm each, involving the dorsum of the right hand, the base of the right 4th finger, and mid-portion of the right 3rd finger which was caused by the SV injury (*Figure 1*) (before treatment) and (Figures 2 and 3) (after treatment). The patient has a moderate sensory loss in the entire right brachial plexus, maximum around the lesions of the right hand.

He also has another ulcer immediately above the left elbow, 5mm/10cm, with the same type of sensory loss over the dorsum of the left elbow (*Figure 4*) (after treatment). He has similar, but less severe, in the distribution of the entire left brachial plexus involving the upper left extremity.

Both ulcerative lesions in the upper extremities show marked hyperpathia and allodynia in the margin of the ulcers along with inflammation, edema, and erythema around the regions of the ulcers.

Deep tendon reflexes in the upper extremities are moderately suppressed. In the lower extremities, the deep tendon reflexes are suppressed especially around the ankles. The feet show marked erythema and marked hypesthesia all the way up to below the knee.

He had occipital nerve irritation on the left side which was treated with an occipital nerve block with 2.5 cc of Marcaine and 10 units of Depo-Medrol ®.

He also had paravertebral nerve irritation with muscle spasm, tenderness, and reddish discoloration of the skin at the level of C6- C7 on the left. This was treated with a paravertebral nerve block with 2.5 cc of Marcaine and 10 units of Depo-Medrol ®.

The patient tolerated all the nerve blocks well with marked relief of pain. There were no complications.

Figure 1. After SV injury and before treatment.

Figure 2. Right hand after treatment.

Figure 3. Right hand after treatment.

Figure 4. Left elbow after treatment.

INFRARED THERMAL IMAGING (ITI) FINDINGS:

Because of cold extremities and non-healing ulcer of the right hand, ITI was done which showed marked hypothermia in the plantar aspect of both feet where the temperature was 23-24 °C at the central part of the plantar aspect areas of relative hyperthermia where the temperature on the right was 27.5°C and on the left 27.1 °C.

These were focal, a few millimeters in size ephaptic hyperthermia which is usually seen in EI typically due to areas of entrance and exit of electricity.

The infrared imaging of the upper extremities showed marked hyperthermia in the distribution of the brachial plexus on the palmar aspect of the left and right forearms.

It also showed marked hypothermia over the dorsum of the right hand where the patient suffers from a large trophic ulcer. The area in the brachial plexus distribution shows a temperature of 34°C especially over the palm and volar aspect of the forearms. This was in contrast to the dorsum of the hand and ulcer area which showed a temperature of 28.5 °C.

The ITI is compatible with the diagnosis of EI entering and exiting the body at the plantar aspects of the feet and causing moderate sympathetic dysfunction over the dorsum of the right hand which culminated in ulceration in the same region.

FINAL IMPRESSION:

The patient suffered for many years due to the exposure to SV which caused damage to his hands, elbows, ears, and legs.

This patient has quite a few stereotypical features of EI involving the peripheral nerves causing moderate neuropathy in the lower extremities, and sympathetic trophic changes in the upper extremities. Also, he has brain stem dysfunction in the form of sensory loss over the right side of the face and left cerebral hemispheric suppression of background electrical amplitude and voltage.

These findings are quite typical of EI.

CASE #3:

The patient is a 41-year-old female who lives on a dairy farm with her husband (Case #2).

CHIEF COMPLAINTS:

She complains of numbness in both arms, pain down the right leg, pain in the right shoulder, and her sleep is interrupted.

Other complaints:

- Headaches.
- Pain behind the right eye.
- Ringing in the left ear.
- Chest pains.
- Pain in the thoracic spine.
- Neck pain.
- Occasional dizziness.
- Blurred vision.
- Poor memory.
- Poor concentration.
- Irritable, edgy, and short fused.
- Low back pain.

HISTORY:

The patient's, symptoms began in 1992. At that time, she was living on a dairy farm. She moved to the farm in the Fall of 1990.

She began to experience pain in the breasts and numbness in her right hand, pain in the right shoulder and the left side of the back. She went to see her family physician. He did not have any explanation for her symptoms.

In November of 1992, the patient went to see a Doctor of Osteopathy. This doctor suggested that she should see a chiropractor. She also told to use a heating pad, and take Ibuprofen. At that time, she had a green leakage from the breasts which was unexplained.

In 1995, she complained of having difficulties with her breathing, and she had leakage from her belly button.

In 1997, she developed a rash behind the neck with peeling of the skin. This was present for almost three months.

In 1998, she was told by one of her doctors to move out of the dairy farm to see if it would help her symptoms.

REVIEW OF SYSTEMS:

Although her headaches have gone from daily while on the farm to three times a week since moving out of the farm to an apartment, they have not changed in severity.

She has been out to the farm no more than once a week. After being there for l 0-minutes, she gets chest pains. She reports there were wiring problems at the farm causing the symptoms due to SV.

Over the abdomen, the patient has a mild sensory loss in the distribution of T-7 to T-l 0 levels mainly to touch and to a lesser extent pain sensation. The umbilicus itself is normal and whatever drainage there was from the umbilicus has stopped, and has healed.

The deep tendon reflexes are mildly suppressed at the ankle levels and over the brachioradialis levels.

Because of cold upper and lower extremities, infrared imaging was done. The infrared imaging shows minimal hypothermia involving the hands, feet, and lower gastrocnemius regions.

Computerized EEG and BER are both normal pointing to no damage of dysfunction in the brain stem.

INFRARED THERMAL IMAGING (ITI) FINDINGS:

The patient had an ITI that showed marked hypothermia in the fingers and toes. The temperature of the right and left first toes was recorded at 23.3 °C. The temperature of the right and left heels shows a temperature of 24.4 °C.

The temperature of the fingers was 24.5 °C bilaterally. These are in contrast to the temperature of the wrist at 27.5 °C and 28.2 °C at the ankles. Also, she had areas of hypothermia in the ulnar aspect of the wrist.

This corroborates with electroporation skin lesions over the dorsum of the left wrist. The infrared imaging shows evidence of sympathetic nerve dysfunction and nerve damage. This is most likely due to exposure to repetitive contamination of electricity while working on the farm on her hands and knees planting vegetables. Also, the patient was exposed to well water on the farm which showed electrical contamination of more than 2-volts direct current.

FINAL IMPRESSION:

This patient, in sharp contrast to her husband (Case #2), has recovered from practically any nerve damage from exposure to electricity. Even the immune system dysfunction and puss secretion from the umbilicus has completely cleared up.

The reason for such a vast difference between the husband (Case #2) and the wife is the fact that since August 1998, they both moved out of the farm. The husband kept going back and forth to the farm daily to feed the cattle. This was not the case with the wife. This improvement proves the benefit of staying away from the farm for nine months.

This patient saved her life by moving away from the farm and at this time has residuals of sympathetic dysfunction from which she suffered while living on the farm.

The neurological and physiologic tests point to residual of the previous exposure to electricity and as long as she stays away from the farm, she should have no problem with it. The painful paraesthesia in the forearms and hands should gradually recover. Recovery could take 2-3 weeks.

CASE #4:

The patient is a 34-year-old female. She was a dairy farmer until September 1997 when she became too ill to work. Before becoming ill, she worked approximately 16 to17- hours a day doing very physical labor, lifting more than 100 pounds easily, seven days a week. Now, she is not physically able to even play with her children.

CHIEF COMPLAINTS:

She suffers from attacks of memory loss, disturbance of immune system, lymphadenopathy. If she stops her medications, she can't walk or talk.

Other complaints:

- Fatigue.
- Severe joint pain.
- Headaches.
- Episodes of "paralysis" in the form of attacks of akinesia.
- Falling spells.
- Weakness of the extremities.
- History of excessive (hair loss, pain all over her body).
- Fibromyalgia.
- Skin ulcers.
- Exophthalmos.

- Bouts of tremors.
- Speech difficulty.
- Neck pain.
- Back pain.
- Skin rashes.
- Reddish discoloration of the skin over the chest, trunk, furuncles, and hives all over her body.
- Severe itching.
- Her feet turn black.
- Sensitivity to cold.
- Pain below the rib cage bilaterally.
- Very cold feet.
- Cyanosis of the feet on and off.

HISTORY:

The patient was in excellent health and very athletic and strong until April of 1996. On that day, she was walking across a field, a clover pasture, out to her cows. She was barefoot at the time. She was hit with a sudden jolt that threw both arms straight out from her body. She saw "fire" come off the tips of her fingers and then she hit the ground. She knows she lost consciousness but doesn't know for how long. The next thing she remembers is getting up off the ground, and being disoriented. She kept shaking her head, trying to get her thoughts together. She headed toward the barn trying to find her husband. She had to hold onto things to keep her balance. When she got to the barn, her husband immediately knew something was wrong because she was looking gray.

Since she and her husband have no insurance, she did not go to a doctor or hospital. She felt she had been electrocuted, but could not understand how this idea could be possible? So, she and her husband called the local electric company to learn what was going on at their farm.

Electricians came out to their farm with meters and told them everything was fine. The electric company employees that came out told her that "she must have hit her funny bone", then left. During this time, many of their cows began getting sick for no apparent reason. They had different veterinarians come out. All kinds of tests were run. Nothing could be found wrong.

She was continuously becoming sicker and sicker. By this time, it was Spring of 1997.

For seven months she and her husband had contacted the electric company to come back out to their farm to do more measurements to find out what was going on.

The electric company finally came back to do some testing. The electric company ran wires around the farm to test for voltage. It was found that there were 3.9-volts of electricity on the metal structural material of the barn as well as the equipment in the barn. It was also found that 62 ½ amps were running from their neutral to their grounding system.

That same day, several trucks came out, and the electric company immediately replaced their transformer and isolated their farm from their neutral. A couple of days later she and her husband received a letter from the electric company stating that the repairs made had completely solved the problem and that they should go ahead and rebuild their herd. Based on that letter, they bought approximately 50 more cows which were thoroughly checked by the veterinarian before purchase.

Approximately two weeks later, they started to have cows drop dead. They would have eyeballs ruptured, holes were blown from the inside of their bodies out, etc. At the same time, the cows began dying, motors on the milking equipment began burning up. They would replace one motor with a new one, and it too would burn up. They asked the electric company to come back again.

When the electric company did the replacement of the transformer, they had put a voltage meter on the barn. At this time, the electric company reported that the readings on the meter were fins and nothing was wrong.

In August of 1997, the meter in their barn melted. The electric company sent out an electrical engineer to replace the meter. The electrical engineer told them he could see that day what was happening. The engineer stated that one of the 120-volt leads was too long, and when the wind blew, it made contact with the guidewire that ran from the pole to the ground, therefore causing the voltage to run through the farm's grounding system as well as through the property itself. He told them why the cows and sheep would die intermittently. Before being told this, they had been told by a veterinarian that the cow's legs above the hooves were burned, but they didn't know why? The explanation given by the engineer explained it. By this time, the patient was in extreme pain and feeling very ill.

In February of 1998, the patient and her husband received a letter from the electric company apologizing for the SV and admitting that they could not fix it.

She went to see her local doctor and he told her to move off the farm because he felt there was no question about the SV on the property.

She and her husband did move off of their farm and stayed in an RV at different family member's houses intermittently, and returned to the farm as they had no place to stay. She would improve while they were gone from the farm, but she did get worse when they returned.

REVIEW OF SYSTEMS:

The patient had rusty discoloration of both feet, purplish discoloration of the soles of the feet. She also has marked neurovascular instability in both lower extremities, from the knees down. The color of the feet fluctuates from minute to minute. She also has mottling of the skin in both lower extremities, more on the left side. All of these are suggestive of neurovascular instability due to sympathetic dysfunction. The mottling also extends up to above the knee bilaterally. The feet are quite cold. She also has very dry hands.

Sweating has been limited to the palms of the left hand, but the rest of the hand and fingers are dry. The skin over the hands is thick and shows multiple areas of small blisters and rashes. The skin rashes extend up to above the elbow or in the left side, and also covers the left brachial plexus region over the lateral aspect of the neck.

The patient also has moderate edema of the skin and subcutaneous tissue in all four extremities.

Cranial nerves examination shows patchy areas of sensory loss in the distribution of the maxillary and ophthalmic branches of the trigeminal nerve, more on the right side.

The patient has moderate neurosensory hearing loss on the right side. The hearing is reduced to approximately 1/3 to 1/4 on the right side compared to the left side.

The sensation in the occipital nerve and posterior cervical nerve roots distribution is markedly reduced and in the same areas, she has moderate cervical paravertebral nerve irritation and moderate occipital nerve root irritation.

In the upper extremities, the deep tendon reflexes are markedly suppressed. Ankle jerks and knee jerks in the lower extremities are moderately depressed. There is no Babinski, no Hoffman's Sign.

The patient has a moderate sensory loss in the thoracic abdominal and thoracolumbar regions on the right side compared to the left side.

The sensory loss on the right side starts at T1- T2 level and goes completely down to T12-L1.

In the precordial region, the patient has rusty discoloration of the skin and moderate sensory loss in the T2-T6 levels more on the right side.

The patient has such marked or vascular instability in the extremities, that from moment to moment, it goes from blotchy to rusty discoloration, and changes to extreme pale to cyanosis.

These have been wrongfully diagnosed as Raynaud's Phenomenon which the patient lacks any sign of. What she has is a moderate dysfunction of the sympathetic system with neurovascular instability of severe nature. It is too diffused at times during the examination up to her groin and axilla which would have no resemblance to Raynaud's Phenomenon.

INFRARED THERMAL IMAGING (ITI) FINDINGS:

The patient had an ITI performed which shows marked hypothermia in the fingers, toes, and feet with the temperature in the fingers and toes being recorded at 24 ° C versus the palm of her hand showing a temperature of 29°C. The plantar aspect of the feet shows hypothermia at 24.4 °C bilaterally, but the central portion of the plantar aspects of the feet shows hyperthermia of 27°C on the right and 26°C on the left. These are typical pathognomonic signs of areas entrance and exit of electricity in the volume of the sole of the feet. The proximal aspects of the upper and lower extremities over the forearms and gastrocnemius regions show a normal temperature of 28.5 ° C-30 °C.

As is noted on the ITI, the patient has two round areas of hypothermia the palms of the hands where the temperature is 29.3°C in contrast to the fingers showing a temperature of 24°C.

The same areas of the point of exit electricity are accompanied by moderate hypothermia and sensory loss. The sensory loss extends up to below the elbows bilaterally in a thermatomal fashion.

The ITI typifies EI with entrance through the feet and exits through the hands.

FINAL IMPRESSION:

This patient has findings typical of EI with entrance through the feet and exit through the hands. As the electricity follows the path of least resistance, it maximally affects the unmyelinated nerve fibers. The most susceptible and thinnest nerve fibers are in the wall of the arterioles.

The electricity follows the blood vessels up to the heart and from there through the upper thoracic nerve roots it enters the spinal cord descending to the pelvic region and affecting the nerves of the bladder which has caused the patient to have urgency and frequency of urination. Also, the ovaries have been affected causing severe pain and heavy menstrual periods.

As the electricity ascended, it has caused brain stem dysfunction resulting in vertigo and poor equilibrium. Following the same pathways, the thermosensory nerves originating from the arterioles eventually terminate in the limbic system involving the temporal frontal regions leading to poor memory, poor concentration, depression, irritability, and agitation all which are present in this patient.

CASE #5:

The patient is a 42-year-old male and a dairy farmer. He is the husband of (Case #4). He has a complex history dating back to the Fall of 1995.

CHIEF COMPLAINTS:

He suffers from vascular headaches four to five times per week with nausea and vomiting. He also has pain in the feet, controlled with medications, with burning, tingling sensation (as if they are asleep).

Other complaints:

- Burning and tingling pain with a numb sensation.
- Episodes of the left side of the body (leg, arm, and left side) numbness as it falling asleep.
- Stiff, painful joints.
- Insomnia.
- Intermittent rash on the face.
- Chest pains to the thoracic spine.
- Seizures. The last seizure was 1-1 ½ - years ago. The area described as full body muscles become stiff, lasting 1-2 minutes. This usually beings with the left-side of the face twitching and induced with stress. Alprazolam controls stress, thereby controlling seizures.

HISTORY:

The patient was exposed to multiple electrical shocks while milking the cows from the Fall of 1995 through March of 1998.

The electrical shocks were received through the cows as they were being "harnessed" to a stanchion, which was a metal apparatus that held their neck so they would not move just before they were milked.

As the patient would touch or lean into the cow, the metal would conduct electricity through the stanchion to the cow's neck, and then to the patient who was in contact with the cow, usually kneeling on his left knee. The cows would jump as this occurred. The patient states that the metalwork is tied into the utility grid to complete the loop.

Around the same period, the cows started dying. The milk productivity dropped by half. The cows were shocked as they touched the stanchion. The cows became very nervous while being milked. The cows started having raw wounded areas of the feet and hooves.

From 1995 to 1998, the patient and his wife became severely depressed, and irritable. Both the patient and his wife developed severe loss of sensation and pain in the hands and feet. They developed attacks of severe chest pain immediately after electric shock.

The patient's wife (Case #4) also received electrical shocks over the same period, as well as a substantial shock in the Spring of 1996. Her injuries caused severe damage, especially to her lower extremities.

The patient's left knee is frequently swollen and his hands have a mottled appearance. The patient describes a tightness in his chest during the shocks and states he was evaluated by a cardiologist in 2000 when he began having chest pain when not being shocked. No cardiac condition was found from the tests.

The patient's primary care physician has been managing his pain. He was referred to a pain management clinic to evaluated and recommend medications and treatments, but his PCP prescribes and treats the patient.

In January of 2000, the patient saw his PCP. He complained of a burning sensation with sweats, but his feet felt ice cold.

In the Summer of 2000, the patient was referred to another neurologist. He diagnosed the patient with complex regional pain syndrome (CRPS) secondary to EI and SV.

In November of 2000, his PCP agreed with the diagnosis of:

- CRPS due to low dose, long-term exposure to EI and SV.
- Headaches.
- Hypertension.

REVIEW OF SYSTEMS:

The patient has a rash on the face that comes and goes. The palms of his hands are mottled.

Cranial nerves, examination reveals 25% neurosensory hearing loss over the left ear. The remaining cranial nerve examination was negative.

The patient has marked paravertebral nerve irritation over the left C6-C7 and left C7-T1 paravertebral nerves.

Examination of the upper extremities also showed marked rusty discoloration of both hands and fingers, and very cold hands and fingers as mentioned above.

He has blotches of the fingers on both sides and marked vasoconstriction from the wrists down to the fingers.

In spite of the poor circulation of the hands, he has extensive cold sweating on both palms of the hands. The combination of cold sweat and very cold extremities is typical of sympathetic damage of long-standing duration.

The patient has classic thermatomal distribution sensory loss in both hands up to below the shoulders in the distribution of brachial plexus on both sides.

The strength of the muscles in the upper extremities, especially both hands were examined with the Dynamometer of Jamar. The dynamometer test showed the grip of the right hand at 39 pounds, and the left hand at 52 pounds.

Examination of the chest and abdomen showed a regional sensory loss in the distribution of C7 through T3 levels on the left side, and sensory loss from C8 through T7 level on the right side. This is typical of spinal cord dysfunction seen in EI patients.

Examination of the lower extremities shows identical poor circulation rusty discoloration of the feet up to below the knees.

He also has thermatomal distribution sensory loss in the distribution of the femoral arteries on both sides up to below the knees.

Deep tendon reflexes are absent in the upper extremities and lower extremities. The sensory loss involves pain, touch, vibration, and position senses in all four extremities.

INFRARED THERMAL IMAGING (ITI) FINDINGS:

The patient had an entire body ITI performed, which shows moderate hypothermia and vasoconstriction exactly over the same left C6-C7 and left C7-T1 paravertebral nerves. This is a classic sign of sympathetic nervous system dysfunction. These two nerves were treated with nerve blocks with 3cc each Marcaine and 2.5mg each Depo-Medrol ®with very good results which helped increase the range of motion of the cervical spine by more than 50%.

Also, the infrared imaging shows marked hypothermia over the fingers and the toes bilaterally. The temperature of the fingers was only 20.9°C on the fingers of the right. hand, and 20.8°C on the fingers of the left hand. This is extremely pathologically cold. The temperature of the dorsum of the hands is 28.6°C on the right and 28.5°C on the left hand. In contrast, the temperature of the forearms is recorded at 30°C on the right and 29. 7°C on the left.

The patient had the same type of marked hypothermia in the toes and feet, as well as the kneecaps where the temperature was recorded at 21°C- over the toes versus 26°C-over the knees.

The infrared imaging is diagnostic of marked sympathetic system nerve dysfunction in the hands and feet.

FINAL IMPRESSION:

This patient has suffered from a chronic irreversible severe sensory nerve damage, which includes both somatic and sympathetic sensory nerves in all four extremities. He also suffered from vascular headaches, hypertension, chest pains to the thoracic spine, seizure, and CRPS which were all due to severe exposure to EI and SV for many years.

COMPLEX REGIONAL PAIN SYNDROME (CRPS)

Complex regional pain syndrome (CRPS) is a chronic and painful condition that affects millions of people worldwide. The main symptom of CRPS is unrelenting burning pain in the affected extremity. Some patients can also have symptoms of an ice-cold extremity. CRPS usually starts after a relatively minor injury or trauma. CRPS can develop from a typical soft-tissue injury (i.e., sprain ankle or wrist); or other, such causes are crush injuries, surgery, repetitive stress injury (RSI), EI and SV injuries are just a few examples of how patients develop this painful condition.

In our study of 824 CRPS patients, we reported 63 patients developed CRPS from electrical injury (EI) (8). In this review, we report one patient developing CRPS due to long-term exposure to SV. CRPS is a complex and difficult disease to treat and manage.

There are four different stages of CRPS. Depending on the nature of the patient's injury, the stages vary in their duration (Table 1).

In CRPS deterioration from stage-I to stage-III was measured in a few weeks up to less than nine months. At stage-II or stage-III it is not at all uncommon for CRPS to spread to other extremities. Stage-IV is almost the flip side of earlier stages and points to the exhaustion of the autonomic and immune systems. With early treatment, the disease may revert to stage-I. Even patients suffering from stages-II or III after proper treatment may revert to stage-I and may look quite normal (8).

TABLE 1. STAGES, SIGNS AND SYMPTOMS OF CRPS (8)	
Stages	***Signs and Symptoms***
Stage I: Dysfunction	Hyperpathia, allodynia, muscle weakness, flexor spasms, thermal changes.
Stage II: Dystrophy	Edema, skin, hair and nail changes.
Stage III: Atrophy	Muscle atrophy, neurovascular instability, cutaneous rash or skin ulcers.
Stage IV: Irreversible disturbance of plasticity, autonomic failure.	Systemic autonomic failure, visceral edema, irreversible low BP, MRSA (methycillin resistant staph. murena infection), elephantiasis, and cancer.

NERVE BLOCKS

In chronic pain patients and EI-SV patients the use of nerve blocks is aimed at relieving pain at the site of nerve irritation. Injection of local anesthetics combined with anti-inflammatories such as Depo-Medrol® helps relieves the pain at the site. The nerve blocks also help release the irritative chemicals such as Nitric Oxide, Substance P, etc., from the areas of nerve irritation. Massage therapy enhances the transmission of these chemicals through the extracellular space, to the blood system, and their excretion through the kidneys. Massage therapy is essential for the success of the nerve blocks.

TYPES OF TESTS USED IN THE DIAGNOSIS OF EI AND SV INJURIES

All electrical injury (EI) and stray voltage (SV) patients require a detail work-up with tests that address the function of the sympathetic nervous system, and tests that are sensitive enough to diagnose damages to the microscopic nerves in the wall of the blood vessels.

Many types of tests are applied in the diagnosis of EI and SV injuries. Some tests are not informative in diagnosing EI and SV injuries and some tests can help identify the pathology and its extent in such patients (Table 2).

TABLE 2. TESTS USED IN THE DIAGNOSIS OF EI AND SV INJURIES	
Type of Test That Are Non-Informative in The Diagnosis of EI and SV Injuries	***Type of Test That Are Informative in The Diagnosis of EI and SV Injuries***
Electromyography (EMG)*	Somatosensory evoked response (SSER)
Nerve conduction velocity (NCV)*	Brain stem evoked response (BER)
Magnetic resonance imaging (MRI)*	Computerized EEG
—	Infrared thermal imaging (ITI)

**Usually, EMG and NCV conduction times are not informative in these types of patients. In, addition MRI usually does not show any typical lesions that can be diagnostic of EI.*

NEURO-INFLAMMATION IN ELECTRICAL INJURIES (EI)

In EI, the electricity is transmitted through the tissues with the least resistance (i.e., arterial blood and thin nerve fibers). As the electricity is transmitted through the blood vessels with the sympathetic sensory nerves in the wall of the blood vessels being involved, reflexly, the sympathetic system causes a rise of blood pressure. The same phenomenon also explains the patient's tendency for the pallor of the skin.

The sympathetic system has three main functions:

- Thermal regulation.
- Neurovascular regulation.
- Modulation of the immune system.

The modulation of the immune system is manifested by the presence or absence of neuro-inflammation. The neuro-inflammation can cause a sterile abscess, cavities, and cysts, as well as skin lesions and breakdown of the skin. This issue is quite common among EI patients.

INFRARED THERMAL IMAGING (ITI)

Infrared thermal imaging (ITI) represents the pattern of heat emission from the surface and deep structures of the body recorded by an infrared electronic heat sensor camera. The thermography in individuals who have had no disruption of the heat emission shows a symmetrical pattern on the right and the left side of the midline.

The non-dominant extremity may be minimally cooler than the dominant side, but this difference is negligible. In pathologic states, the linear isometric pattern of temperature distribution is disrupted showing asymmetry in thermatomal, or dermatomal distribution. The pathologic area may show areas of increased or decreased heat emission (hyperthermia or hypothermia). The camera sensor is also capable of producing black & white views which may add more information regarding any dermatomal nerve root dysfunction.

The role of ITI in pain management was studied in 762 successive complex pain patients evaluated with ITI (9). The results were compared with a meta-analysis of medical literature. A Bales Scientific Infrared Thermal Processor was utilized in this study. The patients were cooled down in a 20-21 °C steady stateroom for 30-minutes of equilibration without clothing. No prior smoking for 90-minutes. A standard sensitivity of 24-34°C was done.

If the areas were not properly visualized the physician would adjust the sensitivity accordingly. Two identically reproducible images recorded on laserdisc were required.

ITI was performed under the following controlled conditions:

- Room temperature 68-71 degrees.
- Thirty minutes equilibration time with clothing removed on examined area of patient allowed for valid heat emission.
- The patient was sequestered from smoking for more than one-hour.
- In accordance with patient's skin temperature, images of varied sensitivities (0.5-1° C difference) were utilized.
- Computerized thermal imaging (Bales Scientific) were obtained and kept permanently in the computer, stored on laser disk.
- The preceding procedure was followed two consecutive times at 15-minute intervals.
- The thermography incorporated the following areas of the body.

CONCLUSION

There is a large lack of understanding about stray voltage (SV) on how it can affect humans and animals. So, it would be fallacious to claim that low voltage electricity would not have caused as much damage.

SV is not simply an issue for dairy farmers here in the United States, it is an issue for many dairy farmers worldwide.

Most medical experts forget to apply the basics of Ohm's law, which states that current, or amperage, is equal to voltage divided by resistance. In humans, the main form of resistance is skin. When the skin is wet or broken, a person's resistance is lowered, meaning the body is affected by low-voltages or currents (10).

The key to understanding how stray voltage affects human health is a better understanding of the effect of electricity on the body.

We have found in the cases that we have reviewed, showed that humid and wet conditions in the dairy operations lower the farmer's resistance, allowing more current to enter their body.

Continued exposure to SV also results in a breakdown of the patient’s immune system among numerous other disorders such as headaches, chest pains, dizziness, hearing loss, poor memory, poor concentration, fatigue, severe joint pain, weakness of the extremities, back and neck pain, skin ulcers, skin rashes, reddish discoloration of the skin, CRPS, and many other symptoms and disorders etc….

In cases, #3 and #4, both saw an improvement of their symptoms from their SV injuries after they moved away from their farms. While their husbands (cases #2 and #5) each went back to their farm daily to tend to their cattle, they continued to have symptoms from the SV.

The cattle on these dairy farms are also victims of SV. They also develop several side effects from exposure SV such as severe anxiety, reduction of milk production, calves being stillborn or born prematurely and underdeveloped, losing weight, eyes and skin issues, and death.

According to Erdreich et al, other researchers have speculated that long-term exposure to SV at levels below from behavioral thresholds damage to the endocrine or immune systems of dairy cattle, thus affecting the health and productivity of the herd (11).

The main thing that misleads doctors and veterinarians in regards to recognizing SV is the fact that they say such a low voltage can't cause this much harm. This thought process is farthest from the truth. There are too many documents cases reporting that SV can cause permanent damage and even death to humans and animals.

SV patients have a poor prognosis. They are often misdiagnosed with either lupus or fibromyalgia. Their only hope for a positive outcome is to receive a proper diagnosis and be treated early and aggressively.

We also have to bring to light that over the years there has been an increased number of reported SV injuries that go beyond the dairy farms. There have been many reported cases of SV on city streets, sidewalks and including cases of metal streetlight poles causing SV in many cities throughout the United States. These cases involve pet owners walking their dogs on city sidewalks where the person, or their dog steps on a manhole cover and gets struck with SV causing the person or dog to receive a serious injury or even die from the SV injury (12-16).

There needs to be a better understanding of the phenomenon of SV. There needs to be more public awareness. Doctors and veterinarians need more education and understanding of this phenomenon. Also, electric companies need to take more responsibility in fixing the areas where SV is reported, may it be on dairy farms or a city sidewalk. These repairs should not take years to rectify. They also have to realize that SV can cause serious and permanent damage or even death.

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