THE NORTHERN HOSPITAL

LIGHTNING INJURY

"The Singing Butler", oil on canvas, Jack Vettriano, 1991, private collection.

Life isn't about waiting for the storm to pass; it's about learning to dance in the rain, (Vivian Greene).

Whispering my goodbyes, waiting for a train
I was dancing with my baby in the summer rain
I can hear him saying "nothing will change"
Dance with me baby, in the summer rain

I remember the rain on our skin
And his kisses hotter than the Santa Ana winds
Whispering our goodbyes, waiting for the train
I was dancing with my baby in the summer rain

I remember laughing 'till we almost cried
There at station that night
I remember looking in his eyes

Oh my love, it's you and that I dream of
Oh my love, since that day
Somewhere in my heart I'm always
Dancing with you in the summer rain

Doesn't matter what I do now
Doesn't matter what I say
Somewhere in my heart I'm always
Dancing with you in the summer rain

I can hear the whistle military train
I was dancing with my baby, in the summer rain
I can hear him singing "Ooh Love Is Strange"
Dance with me baby, in the summer rain

I remember the rain pouring down
And we poured our hearts out as the train pulled out
I can see my baby waving from the train
It was last time that I saw him in the summer rain

Oh my love, it's you that I dream of
Oh my love, since that day
Somewhere in my heart I'm always
Dancing with you in the summer rain

Doesn't matter what I do now
Doesn't matter what I say
Somewhere in my heart I'm always
Dancing with you in the summer rain

Every time I see the lightning
Every time I hear the thunder
Every time I close the window
When this happens in the summer

Oh, the night is so inviting
I can feel that you are so close
I can feel you when the wind blows
Blows right through my heart

Oh my love, it's you and that I dream of

Oh my love, since that day
Somewhere in my heart I'm always
Dancing with you in the summer rain

Every night and every day now
Though I know you've gone away
Somewhere in my heart I'm always
Dancing with you in the summer rain

"Summer Rain", Belinda Carlisle, 1989

"The Singing Butler" was the best selling print in Europe in the early 2000s, more popular even than Monet's Water Lilies or Van Gogh's Sunflowers, and it has helped to amass a multi-million pound fortune for the man who painted it. Jack Vettriano went from total unknown, whose paintings sold for a just a few hundred dollars at most, to multi-millionaire, earning over half a million dollars a year in royalties alone, in the space of less than 10 years.

In 2004 the original "Singing Butler" was sold by Sotheby's of London, for 744,500 pounds. The enormous public appeal of his works is rooted in his romantic depictions of nostalgic love scenes from the 1920s and 1930s. In the "The Singing Butler" we see the quintessential essence of Vettriano. Two lovers are dancing together on the beach, oblivious to the rest of the world around them, even to their own servants who strive to protect them from the rain. So why is it that Jack Vettriano is not more widely recognized around the world for his "genius"? Despite his huge popular appeal the art "establishment" and "critics" seem to deride his work. None of the great national galleries of the world, such as the Tate of London hold any of his works. Reference books either ignore him or grant only a passing mention.

In October 2005, it was discovered that many of Vettriano's paintings, including "The Singing Butler", were little more than colored copies of figures from a cheap £16.99 artists' reference manual, "The Illustrator's Figure Reference Manual" published in 1987. Not only his most famous painting, but also a number of his other works, appear to be based closely on sketches of models posing in the book as shown opposite. Look familiar?

The "experts" claim Vettriano is little more than a copyist and colourer, yet there can be no denying that the "public" love him immensely. Jack Vettriano himself simply ignores the criticisms of the "experts" and continues to produce his masterpieces. The whole debate echoes the age old issue illustrated best in the story of Florey and Fleming, of what is it that constitutes "genius", the one who first discovers, or the one who "makes something" of the discovery. In truth the answer is really both, without the initial idea nothing will ever happen, yet without the one who "sees further" and "acts" there will be no value in the discovery. Vettriano may indeed be a copyist, but his genius has been to give life, context and deep meaning to what were otherwise isolated, lifeless and meaningless figures in a manual.

The figures in Vettriano's painting are oblivious to all around them in their moment of intimacy, even though the butler has ensured that the entire party has been put at risk of their lives! His upraised umbrella placed near the water's edge whilst in the "summer rain" has put the entire party at risk of a side flash disaster should lightening strike! Yet it is human nature that this risk is trivial, even irrelevant when it comes to matters of the heart.

If ever we are to encounter the mass casualties of a lightening strike, we will do well to remember the deep meaning that Jack Vettriano shows to us in his works. Even though the casualties may initially appear dead with fixed and dilated pupils like the figures from an "Illustrator's Manual" we must ignore the "perceived wisdom of the experts" and proceed with CPR in any case. There will be a brief window of opportunity for some of these victims whereby our CPR may yet, like a Vettriano masterpiece, bring life to a lifeless figure.

"Fire Starter" Canberra 16th January 2003, (Chris Arndt, Extreme Weather, Viking 2006)

LIGHTNING INJURY

Introduction

Left: Cumulonimbus (thunder) clouds. Right: Hannibal's Army caught in severe storms as he crosses the Alps (note the threatening Cumulonimbus clouds). JMW Turner, oil on Canvas, 1812 Tate Gallery London.

Spectacular example of Lichtenberg flowers (NEJM, 2000; 343:1536)

Lightning is produced most commonly in **cumulonimbus** (thunder) clouds.

Updrafts and downdrafts in such clouds carry ice particles and water droplets.

Collisions between these particles create static electricity with large negative charges building up at the bottom of clouds.

A potential difference develops between the negatively charged cloud and the positively charged ground.

A discharge of lightning occurs when the insulating effect of the surrounding atmosphere is exceeded by this potential difference.

History

In the pre-Enlightenment age - before an understanding of the nature and physics of electrical energy, lightning was most commonly attributed by many cultures to a terrifying expression of the wrath of the gods, (or God).

Physics

The voltage of lightning can range from **2 million** to greater than **100 million volts**!

The average is approximately 10 - 30 million volts. Human produced electricity rarely exceeds 70,000 volts.

The current generated can reach beyond **100 - 200,000 amps.**

Ohm's Law:

From Ohm's law: **V = I x R**

I = V/R

- It is the current (**I**) that determines the degree of tissue damage.

  It is directly proportional to the voltage and inversely proportional to the resistance.

- Lightning behaves as a "cosmic" **DC** (as opposed to AC) counter shock.

  It induces **asystole** rather than VF which tends to be the case with household AC current.

- Lightning has only very **brief duration**, at **0.1 - 10 msecs.**

  This is rarely enough to result in skin breakdown and most of the current "flashes" over the body. This phenomenon is known as "flashover".

- Human produced electricity on the other hand tends to have relatively long exposure times which results in skin burns with breakdown and *internal passage* of current with entry and exit wounds.

  Lightning rarely shows these types of wounds. Despite the flashover phenomenon enough current none the less may enter the body to cause serious cardiovascular and neurological injury.

Pathophysiology

Types of Lightning Strike:

These may be:

1. Direct strike.

   - This is the most severe injury as most of the current discharges directly through the body.

   - The likelihood of direct strike is increased by metal objects being worn or carried, (for example umbrellas).

2. Side flash.

   - This occurs when after a primary strike to an adjacent object such as a tree light pole or building, or person, then further discharges to an adjacent victim.

   - It occurs when the strike object has a relatively greater resistance to the lightning current than the air between the object and the victim.

   - It can contribute to the occurrence of simultaneous injury to multiple individuals from a single lightning strike.

3. Flashover.

   - This phenomenon occurs when the majority of the energy flows *over the surface* of the victim rather than *through* the victim.

   - It may also result in body surface water (such as sweat or rain water) vaporizing and causing steam burns.

   - Clothing may ignite causing secondary thermal burns.

   - Clothing may be blasted off.

   - Thermal burns may also result from instantaneous super heating of any metal objects worn by the victim.

4. Ground current, (step or stride voltage).

- This occurs when lightning strikes the earth and spreads through the ground toward the victim.

  The victim may have one leg in contact with the ground closer to the strike point than the other leg, producing a potential difference (or "stride potential") between the legs.

  The result is passage of current up through one leg into the trunk and down again through the other leg.

5. Blast injury, (see also Blast Injury document in Surgery - Trauma folder).

   - Lightning may also cause significant **blast type injury**.

     The local atmosphere can be instantaneously super heated to as much as 8000 - 30,000 degrees Celsius, causing rapid expansion of air with a resulting shock wave (thunder), followed by rapid cooling and implosion.

     Significant secondary, tertiary and quaternary blast injury may result.

Clinical Features

Contrary to popular belief, lightning strike is not uniformly fatal.

The **mortality** rate is approximately **30%,** whilst in survivors the **morbidity** rate is approximately **70%.** [1]

The surprisingly high survival rate, given the energy levels of lightening is related predominantly to 2 factors:

- The extremely brief duration of the strike.
- The "flashover" phenomenon.

Most lightning strikes are unwitnessed and the diagnosis will be difficult in the unconscious or confused patient.

Features suggestive of a lightning strike include:

1. History of recent thunderstorm.
2. Outdoor occurrence of the incident.
3. Tympanic membrane rupture.
4. Presence of Lichtenberg flowers.
5. Partial or complete clothing disintegration.
6. Multiple victims

Effects of lightning injury may include the following:

1. Asystole which lasts seconds to minutes, usually with a spontaneous return to sinus rhythm.

2. Apnea due to direct effect on medullary centers.

    - This may last hours or even days and the patient may therefore need prolonged ventilation.

      Because this respiratory arrest is long lasting as compared to the asystole a secondary hypoxic cardiac arrest can occur, if respiration is not supported during this phase.

3. Neurological deficits:

    - Confusion.
    - Amnesia.
    - Coma, which may be prolonged.
    - Autonomic and peripheral nerve dysfunction.
        - ♥ The usual signs of brainstem dysfunction such as fixed and dilated pupils are **unreliable** in cases of lightening strike.
    - A global transient paralysis may occur where patients may be aphasic and unable to move.
        - ♥ This is usually transient and resolves within minutes but may take up to 24 hours.

4. Secondary trauma

    - Direct injury
    - Blast injury (*especially tympanic membrane rupture*)
    - Thermal burns due to:
        - ♥ Superficial steam burning.
        - ♥ Burns due to heated metallic objects.
        - ♥ Secondary to clothing igniting.

5. Hypothermia may be an issue in patients exposed to cold weather for a prolonged period.

6. Keraunoparalysis:

- This is lightning induced neurovascular injury occurring in a limb, (usually the lower limb) and is a *common* consequence of lightning strikes.
- It appears to be caused primarily by **vasospasm** of the arteries within the limb.
- It is common and characterized by:
  - ♥ Flaccid paralysis.
  - ♥ Complete or partial sensory loss.
  - ♥ Vascular compromise, with pale, mottled and pulseless limb.
- The condition is usually self limiting and most commonly resolves within **1-6** hours.

  If symptoms haven't resolved by 24 hours other causes or secondary complications need be considered.

7. **Lichtenberg flowers**, (**see photograph above**):

- These may appear immediately but more often take several hours to develop.
- They are not true burns but areas of inflammation due to "electron showers" over the body during a flashover - they usually fade within 24 hours.
- They occur uncommonly but are **pathognomonic** for **lightning injury**.
- They are **not** caused by household electrical injuries.

8. Other injuries occuring less commonly include:

- Vestibular dysfunction
- Sensorineural deafness
- Optic nerve damage, retinal detachments
- Myoglobinuria and hemoglobinuria may occasionally occur.
- Later development of cataracts (these occur more commonly than in electrocution injuries)

9. Lightning strike in pregnancy has a high rate of fetal death in utero, despite maternal survival

Investigations

These will be directed according to clinical findings.

Consider the following

Blood tests:

1. FBE
2. U&Es / glucose
3. CK / myoglobin
4. LFTs / lipase
5. Troponin I.

ECG:

Look for arrhythmias or other signs of cardiac injury.

Plain radiology:

Trauma series plain x-rays as indicated.

CT scan brain / CT angiogram / MRI

CT scan brain for any altered mental status (secondary injury may have occurred as well as that induced by the lightning)

Management

Prevention:

General Considerations:

General lightning safety recommendations for **high risk weather conditions** include:

1. Developing a proactive approach that includes monitoring the local weather from the day before activity until play has finished and the crowd has dispersed.
2. Establishing a specific chain of command. This includes choosing a designated weather-watcher and specifying the method of warning the people at risk.
3. Defining and listing safe structures and locations.
4. Defining the criteria for both suspension and resumption of activity.

Safe Structures:

It should be noted that **no place** is *absolutely* safe from lightning; however, some places are safer than others.

Examples of (relatively) safe structures include:

1. Large fully enclosed buildings (with electric and telephone wiring and plumbing to provide a safe pathway for the current to the ground).

2. Fully enclosed metal vehicles (car or buses):

   Note that it is *not* the rubber tires that are protective, rather protection arises from a phenomenon known as the "**Faraday Cage**".

   In general terms lightning, effectively "flashes over" the *external* surface of the metal vehicle which conducts it directly into the ground. Within the vehicle (or Faraday Cage, there is no electrical field and so the occupant is largely protected).

   However, not all vehicles are the same. Convertibles for example do not have metal roofs, which compromises the Faraday cage affect. Additionally some vehicles are manufactured out of non-metal parts, which impedes the ability of lightning to flash over the car.

   Also some portions of the current can flow through the vehicle's electrical systems and internal metal components including radios, mobile phone chargers, GPS units, car door handles, foot pedals, the steering column and steering wheel.

   If driving, pull to the side of the road, turn on the hazard lights, turn off the engine and wait out the storm. Hands should be folded in your lap and avoid touching anything metal within the vehicle. Avoid touching the radio or talking on a mobile phone, especially if it is connected to the vehicle. Once the electrical current has passed over the vehicle and entered into the ground, the car is not "electrified" and it will be safe to exit the vehicle, (all else being equal of course).

   Buses are an excellent shelter and can be strategically placed around a venue to protect larger groups of people.

Unsafe situations:

These include:

1. Open fields:

   - If outdoors the 'lightning position" may be used as a last resort: crouched with feet together to make one contact point (thus avoiding "stride voltage").

2. Elevated areas such as hills

   - Keep to a valley, ravine or other low area.

3. Close vicinity to the **tallest structure** in an area (e.g., tree, communication tower, light pole), especially **isolated** tall structures.

4. Small structures such as rain/picnic shelters, tents, interchange benches.

5. Bodies of water including swimming pools (including indoor or outdoor)

6. Proximity to electrical conductors:

   - Stay away from objects that conduct electricity in general: e.g. barbed wire fences, power lines, windmills).

7. Umbrellas, golf clubs, bats, or any other object that increases an individual's height, (especially if metallic).

8. Concrete floors or walls.

   - Lightning can travel through any **metal wires or bars** in concrete walls or flooring.

9. Avoid electronic equipment in general:

   - Lightning can travel through electrical systems including computers, radio and television reception systems and corded (i.e "land line") phones Cordless or mobile phones are safe to use during a storm.

10. Huddled groups:

    - Ideally space individuals > 6 meters apart

The "30/30" rule:

The "**30/30**" rule is recommended for lightning safety and serves as a guide for the suspension and subsequent resumption of outdoor sporting activity.

The first part of this rule (a flash-to-bang count of 30 seconds) is a guide to the suspension of activity. The flash-to-bang count is a practical technique for estimating the distance to lightning activity.

It relates to outdoor sports activities, but of course can also be applied more generally to anyone outdoors in high risk weather conditions.

In *general* terms, a **flash-to-bang count** of **30 seconds** indicates that lightning is about **10 km away**.

This is associated with a significant risk that the next strike could be at the observer's location.

Outdoor activity should thus be suspended and people should move to a safe place.

A flash-to-bang count of < **30 seconds** indicates that lightning is < **10 km away**.

The rational for the Flash to Bang count (or 30/30 rule), is as follows: [4]

- **The aim is to seek shelter when the lightning activity is too close, but how do we define what is meant by too close?**

- **Light** travels (very much) faster than sound - when lightning flashes in the distance, we see it virtually **instantaneously**, whereas **sound** travels far more slowly, at around **1 kilometer every 3 seconds**

- The time that elapses between the flash of lightning to the clap of thunder can therefore be divided by three to give an estimate of how far away the storm is in kilometers.

- Currently, most experts agree that the accepted "safe" distance from a thunder storm is **>10 kilometers.**

  This means that as the flash-to-bang count approaches 30 seconds, all people at risk should seek a safe shelter.

  (i.e, **30/ 3 = 10 kilometers**) - the shorter the flash to bang count in seconds is, the closer is the lightning source.

- The second part of the 30/30 rule provides the criteria for resumption of play. Here it is recommended that people wait **30 minutes after the last sight of lightning or sound of thunder**. This figure is based on the observation that a typical storm moves at about **40 km/hour** Thus, waiting 30 minutes allows the thunderstorm to be about **20 kilometers away**, (**so about twice the minimum safe distance**) thus minimizing the probability of a nearby strike.

  It is important to emphasize that blue skies and lack of rainfall are not adequate reasons to breach the 30 minute return-to-play time limit - (beware the proverbial "bolt from the blue").

Lightning Rods:

Lightning rods (and the accompanying protection system) are designed to protect a house or building from a direct lightning strike and, in particular, a lightning-initiated fire.

Note that lightning protection systems do not prevent lightning from striking the structure, but rather intercept a lightning strike, provide a conductive path for the harmful electrical discharge to follow (the appropriate UL-listed copper or aluminum cable), and disperse the energy safely into the ground (grounding network).

It's very important that these components be properly connected (bonded) to minimize the chances for any sparks or side flashes.

While lightning rods help protect a structure from a direct lightning strike, a **complete** lightning protection system is needed to help prevent harmful electrical surges and possible fires caused by lightning entering a structure via wires and pipes. A complete system also includes electrical

surge protection devices for incoming power, data, and communication lines; and surge protection devices for vulnerable appliances. Lightning protection may also be needed for gas piping.

(http://www.lightningsafety.noaa.gov/lightningrods.shtml)

Pre-hospital:

In contrast to other mass disasters immediate attention should be given to those who are **most** unwell, even apparently dead, (this approach has been described as "**reverse triaging**" - when compared to traditional priorities).

Immediate CPR for arrested patients.

- It is important to dispel the myth to first responders that victims of a lightning strike are "charged" and so dangerous to touch.

Ongoing ventilation during the prolonged period of apnea, following the return a spontaneous cardiac output, will prevent a secondary hypoxic cardiac arrest.

Fixed and dilated pupils should not be taken as evidence of brain death in the first instance following a lightning strike.

Emergency Department:

1. Immediate ABC issues, ongoing CPR as required:

2. Treat as for potential multitrauma, including possible blast injury, check tympanic membranes.

3. Treat any burns along usual lines.

4. Check for hypothermia if weather conditions are relevant to this.

5. Remember that signs of brain death may be unreliable in the first instance.

Disposition:

Patients with ECG changes or abnormal echocardiography should have ongoing ECG monitoring and be referred to the Cardiology Unit.

Burns should be referred to specialist Burns Unit

Ocular injuries are referred to Ophthalmology

Hearing impairment cases are referred to the ENT unit

Other complications such a trauma or vascular injury are referred to the Surgical or Vascular Units as clinically appropriate

Patients with behavioural / anxiety symptoms should be referred for neuropsychiatric follow up.

Appendix 1

Three levels of alert for lightning safety were used for the **Sydney Olympic Games** of **2000.**

These were:

Yellow: State of increased lightning awareness:

Intended to give 60 minutes advanced warning of a storm front reaching 10 km from a venue.

The direction and speed of travel of the storm front are taken into consideration, so that the anticipated time taken for the storm to reach 10 km from the venue is 60 minutes.

Orange: Activation of the lightning protection plan:

Intended to give 30 minutes advanced warning of a storm front reaching 10 km from a venue.

Depending on the venue's requirements, all competitors should be moved to protected areas.

Patrons should be advised to remain in position if they are already in a safe area, or move to a protected area as shown on a map.

Individuals in transit should be advised to complete their transit as soon as possible. People in cars and buses should be advised not to commence transit and to remain in their vehicles.

Red: State of increased lightning risk:

Declared when lightning activity is within 10 km of a venue.

By this stage, all movements and evacuations should be complete, with the venue now secure from lightning.

Lightning spectacularly strikes the elevated dome of St. Peters, just hours after the abdication of Pope Benedict XVI, on 11 February, 2013.

On 11 February 2013, Pope Benedict XVI shocked the world by announcing his abdication in a speech in he gave in Latin before his cardinals, citing a "lack of strength of mind and body" due to his advanced age. He was the first Pope to (voluntarily) abdicate the Papacy since Pope Celestine V in 1294. Celestine V today is revered as a Saint of the Catholic Church. His famous contemporary, Dante Alighieri, however, was not quite so impressed with Celestine, placing him in the zone of the Neutrals, at the very gates of the Inferno!

In past ages lightning was almost invariably attributed to the wrath of God - perhaps God was not particularly impressed with Celestine either especially in regard to the precedent he set in the Fourteenth century, and so made his agitation quite clear to Benedict !

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