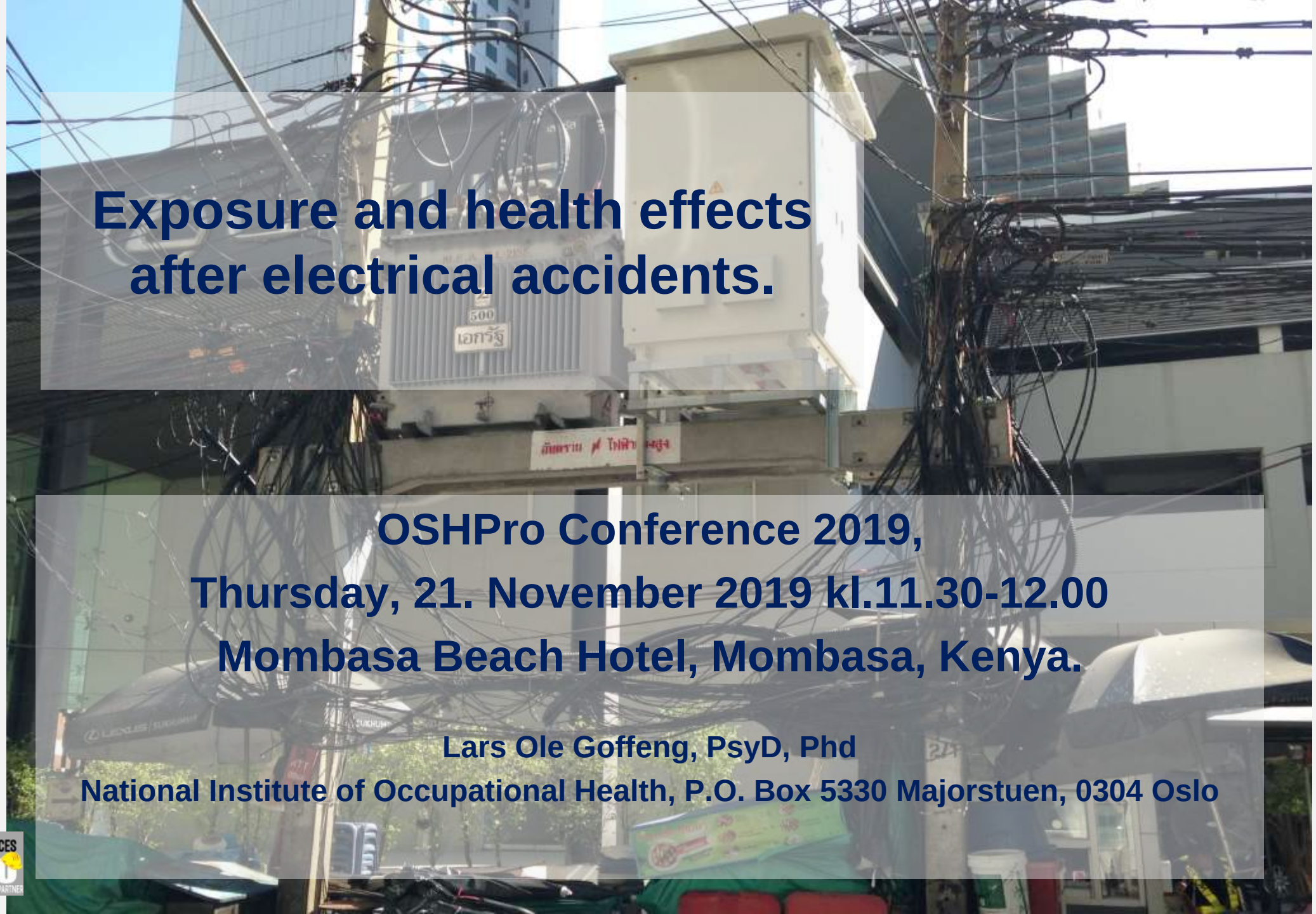


Exposure and health effects after electrical accidents.

OSHPro Conference 2019,

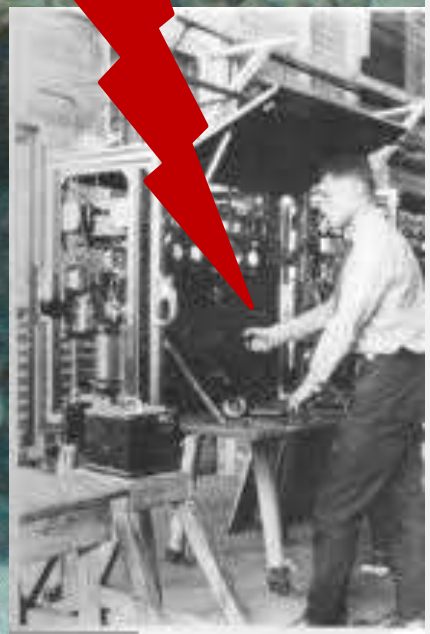
Thursday, 21. November 2019 kl.11.30-12.00

Mombasa Beach Hotel, Mombasa, Kenya.

Lars Ole Goffeng, PsyD, Phd

National Institute of Occupational Health, P.O. Box 5330 Majorstuen, 0304 Oslo

International Health Exhibition, London, 1884



THE POST-MORTEM APPEARANCES IN A CASE OF DEATH FROM THE ACTION OF ELECTRICITY.

By MARMADUKE SHEILD, M.B., F.R.C.S., and SHERIDAN DELÉPINE, M.B., B.Sc.

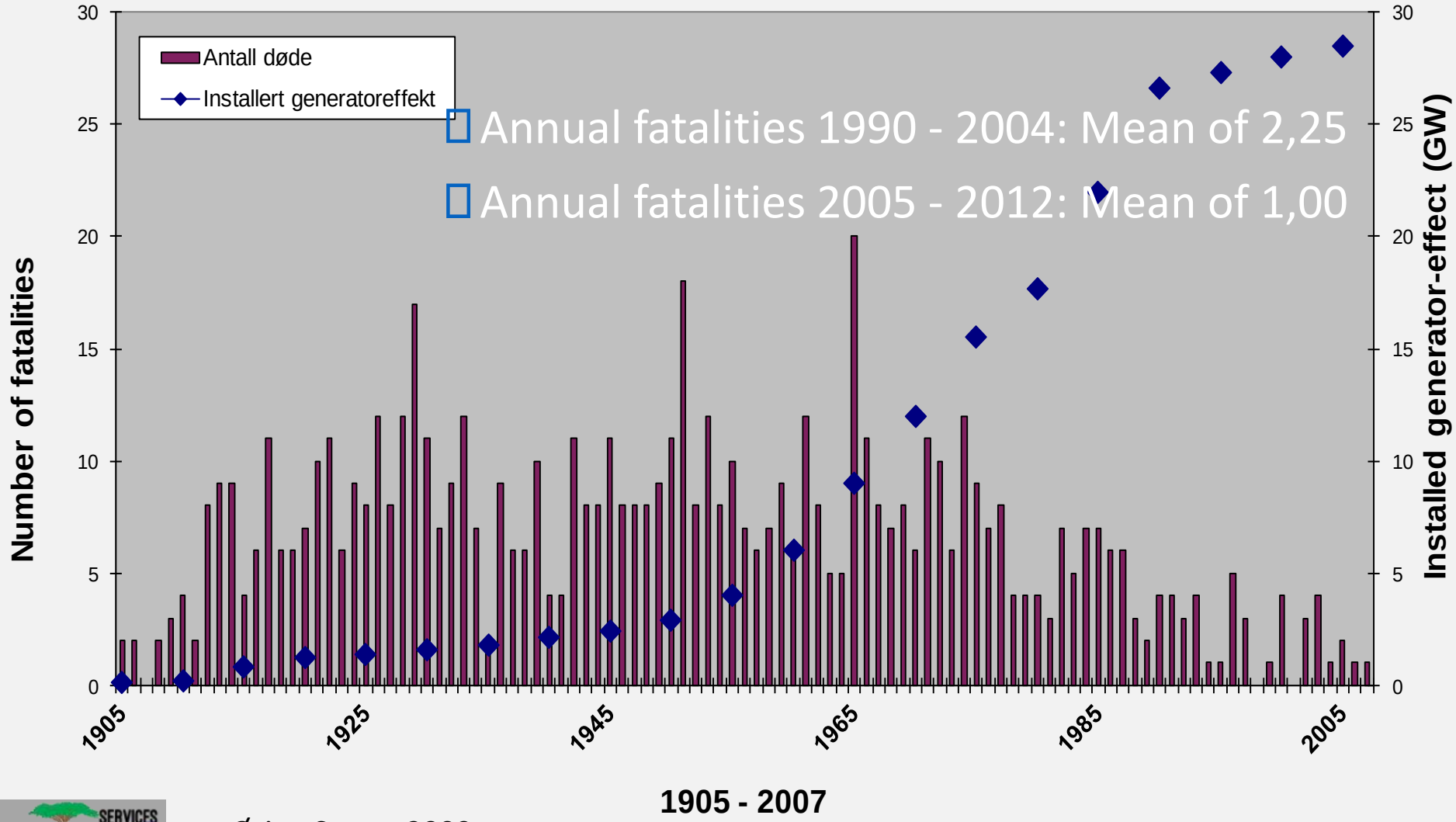
(For permission to publish this case we are indebted to Dr. Cavafy.)

A HEALTHY strong man, aged 21, engaged at the electrical department of the Health Exhibition, was observed to suddenly fall back insensible from a machine which he was manipulating. He was at once brought to St. George's Hospital, on the evening of September 27th, 1884, and was found to be quite dead on admission. No alteration was perceptible in the texture of his clothes or the metallic substances on t

Although at least two fatal cases have been reported in this country from the action of the electrical fluid generated by machinery, yet we are not aware that the pathological changes have been placed on record.

Looking at the present increase in the application of electricity to various purposes, it seems quite probable that fatal accidents will increase among those who, from the nature of their vocation, are daily engaged among the complicated machinery.

Fatalities from electricity or light-arc accidents in Norway 1905-2007/2012

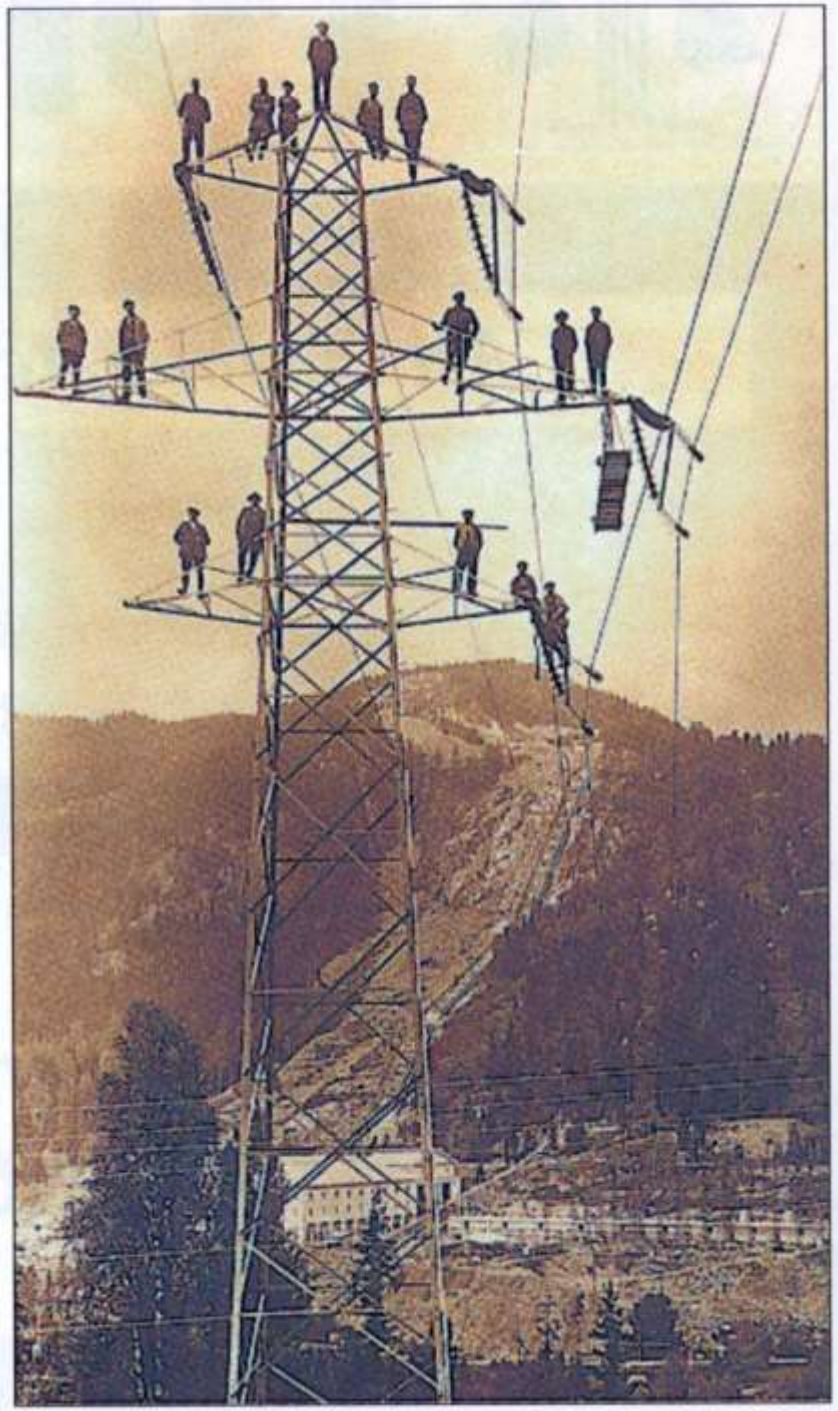


But what about less serious accidents? Do they approach a zero-level as well?

Under-reporting:

50-500-3000-100.000

Ørjan Steen, 2009
Frode Kyllingstad, 2013



Most exposures to electricity have no serious consequences!

-but when?
-and why?

You can't predict that prior to an accident…

That is why it's important to prevent exposures and accidents from occurring!

Exposure, health effects, and follow-up after electrical accidents

- Exposure characteristics
- Acute injury mechanisms
- Injuries after electrical accidents

About acute effect-mechanisms …

Exposure to electricity

Electrical accidents in brief

- Low current – Power current
- Low voltage – High voltage
- Alternate current – Direct current
- Current flow
  - Current path
  - Duration
- Arc from current

Behavior- and health indications of exposure?

- Burns/blisters in contact-points?
- «Thrown away» from power source?
- Contractions holding you on to the power source? **Duration of exposure**
- Blood tests at right point of time?
- ECG – Signs of arrhythmia?

A «joker»:
Amperage depends on resistance in points of contact and in body tissue!

I=U/R

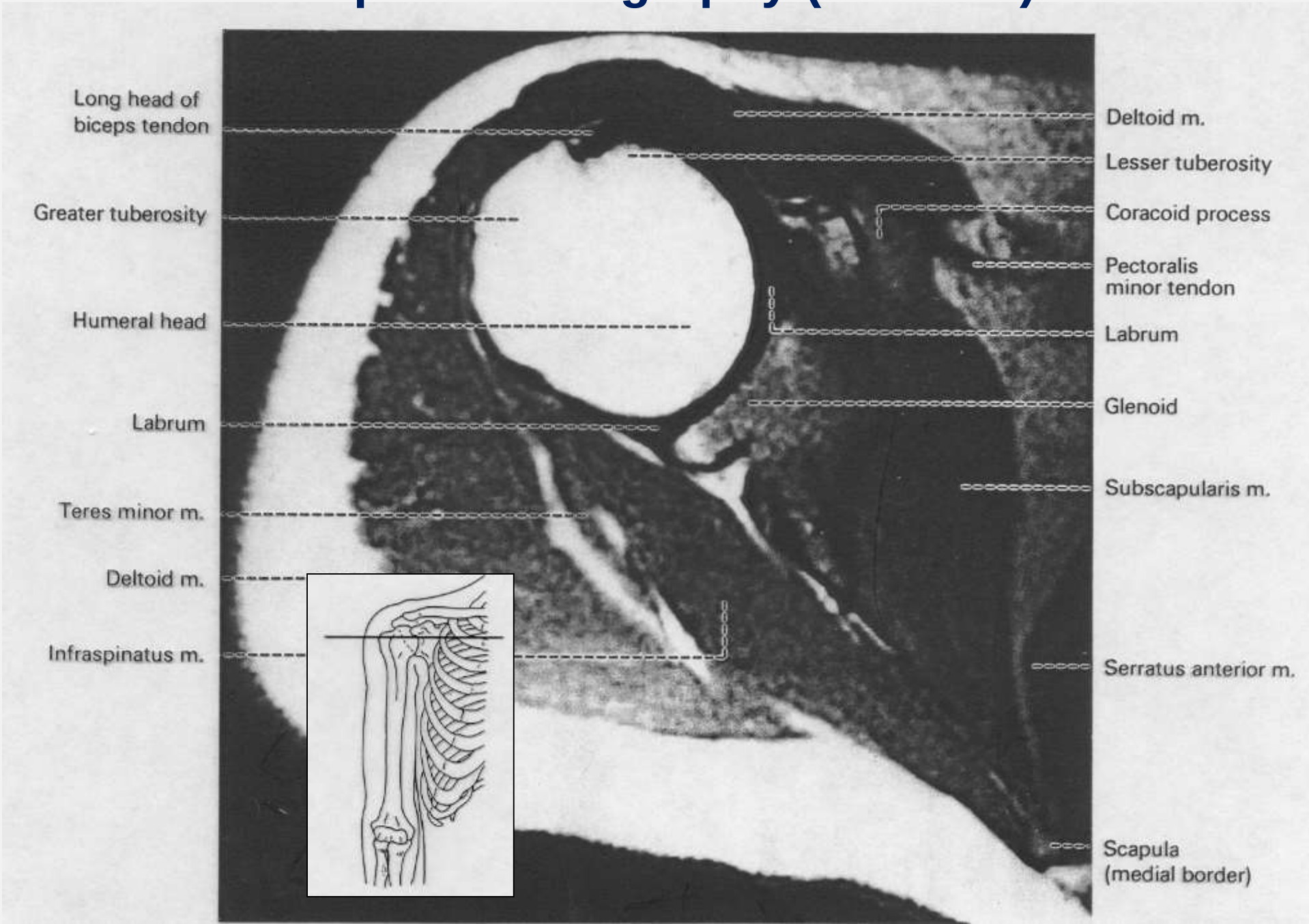
- **Moisture/area?**

- Nerves
- Blood vessels
- Muscle
- Skin
- Tendons
- Fat tissue
- Bones

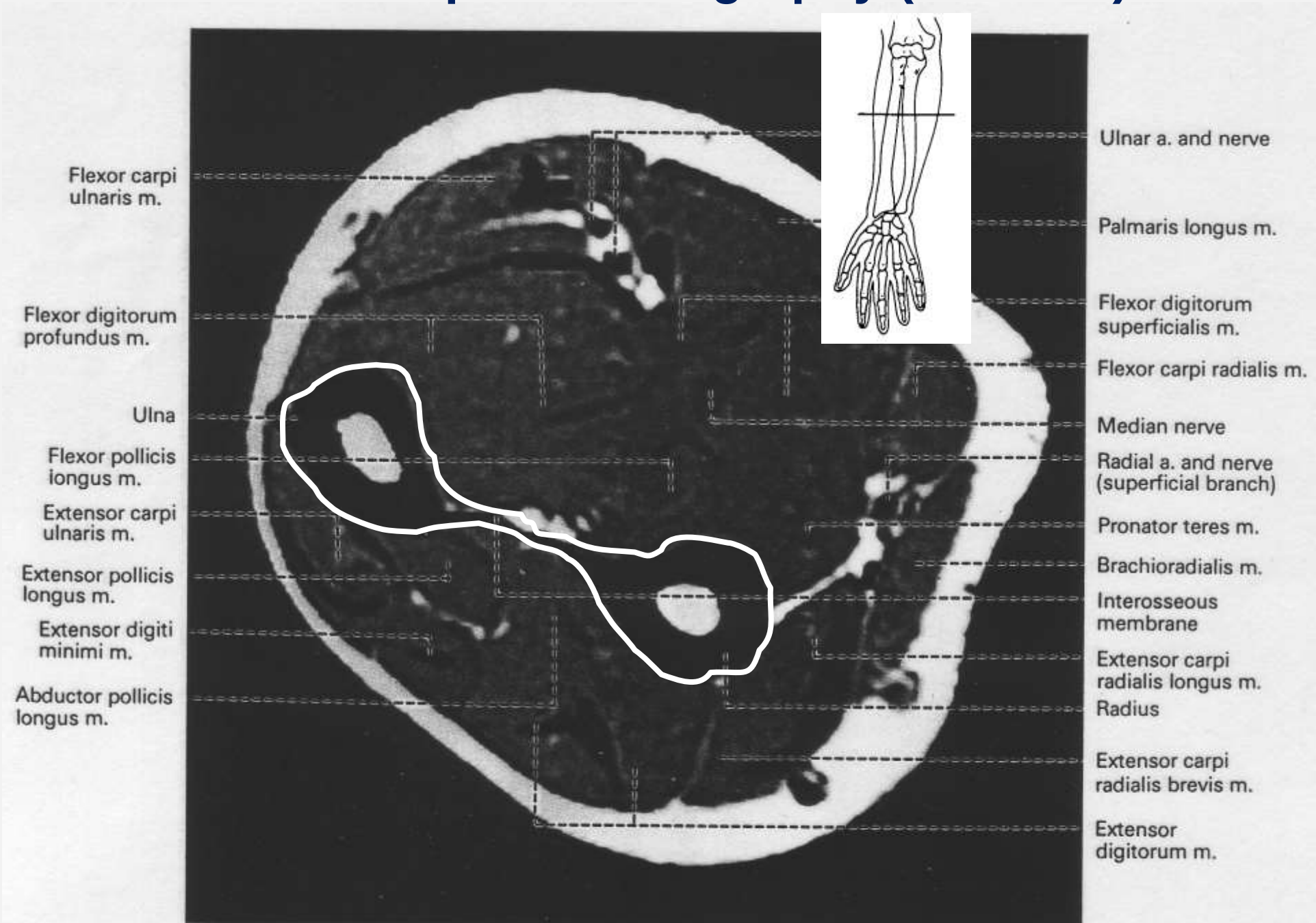
Different body tissue

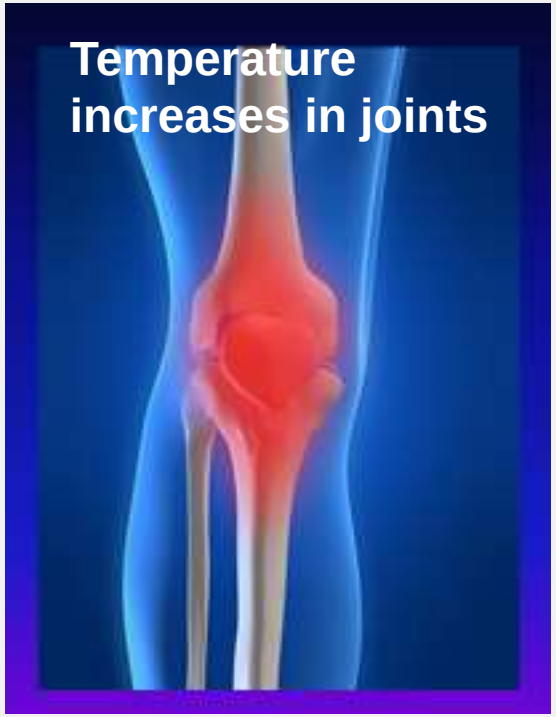
Increasing resistance

Computer tomography (CT-scan) shoulder …



… and computer tomography (CT-scan) arm…





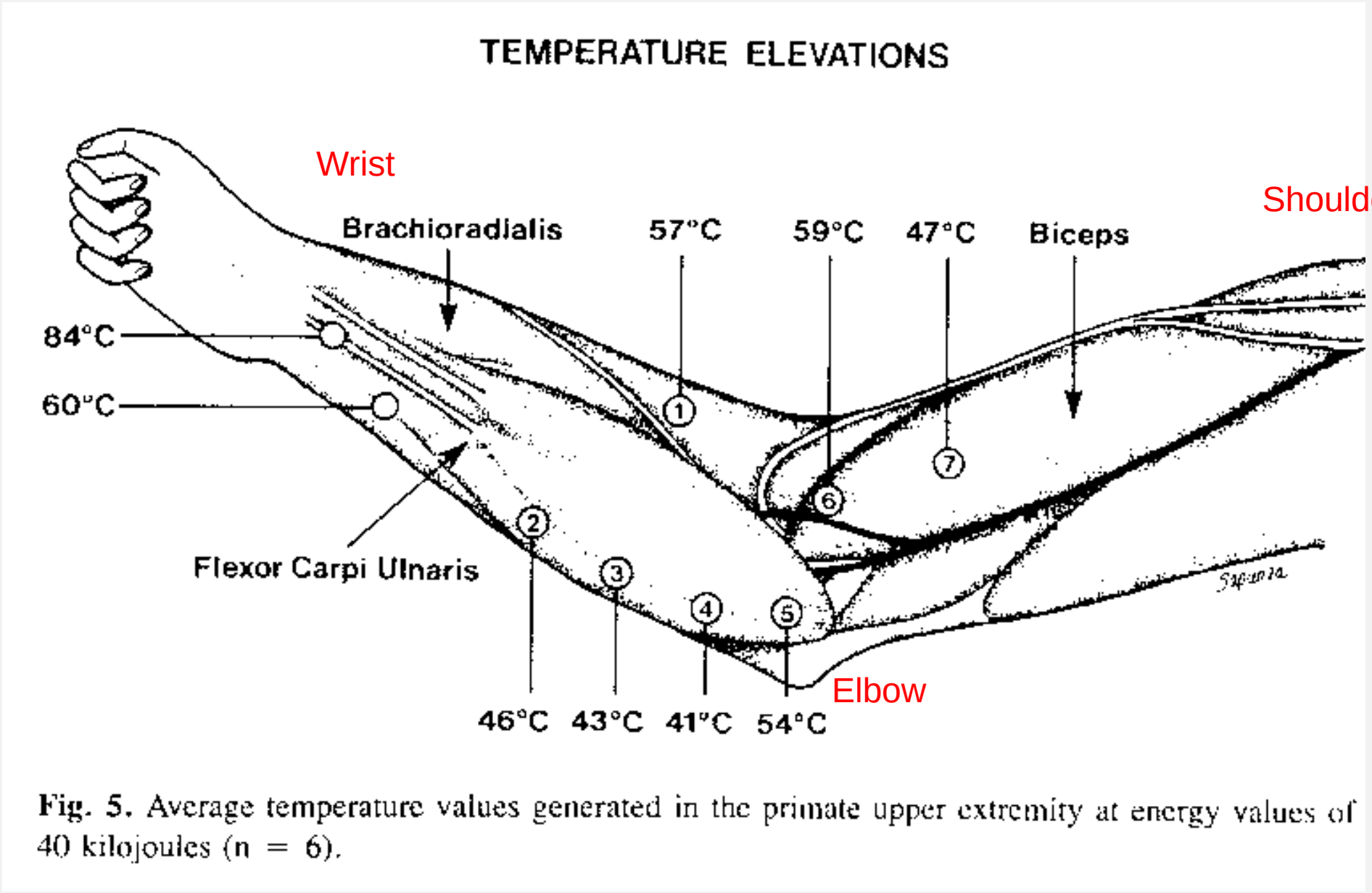
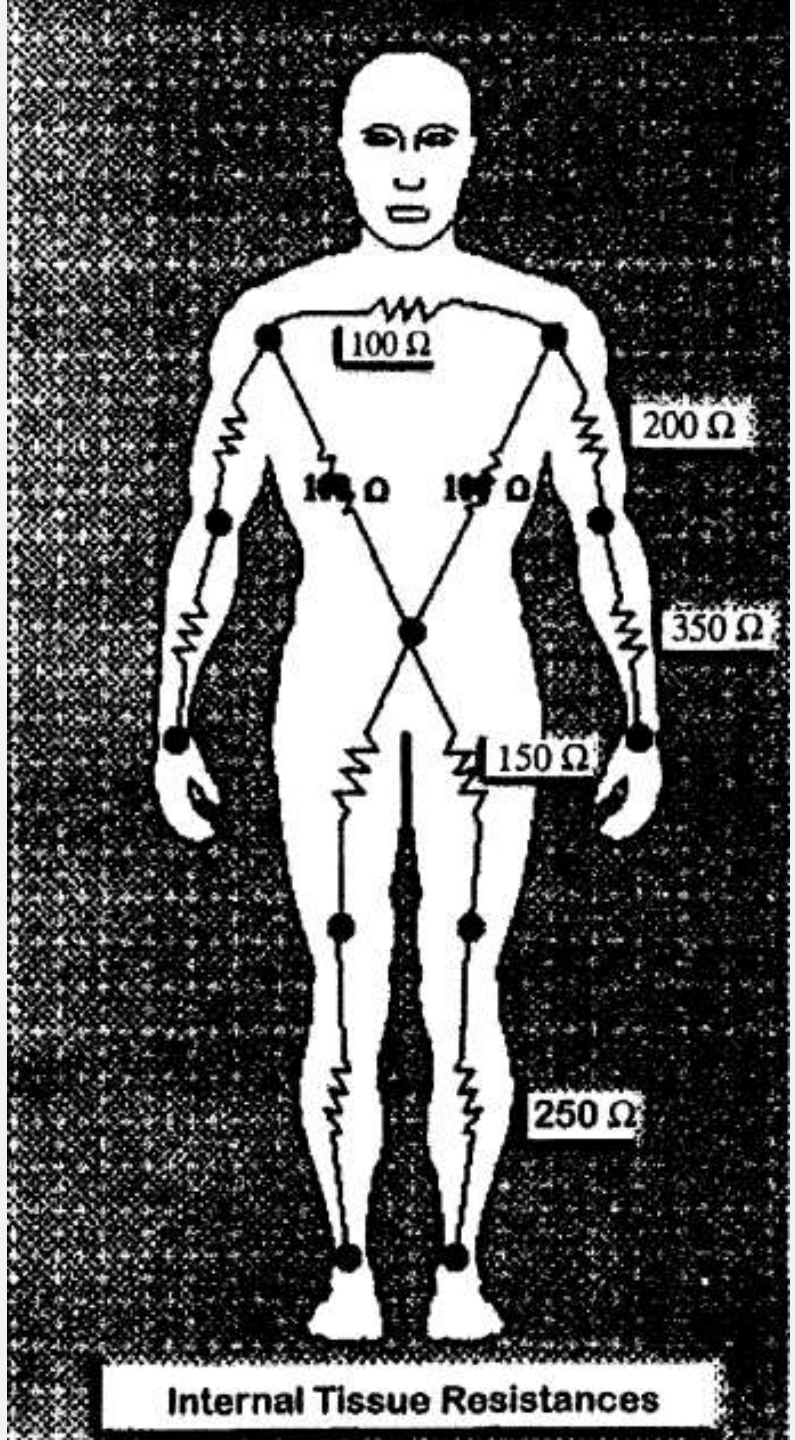


Fig. 5. Average temperature values generated in the primate upper extremity at energy values of 40 kilojoules (n = 6).

Voltage arm to arm: 3525 V - 4,5 A for 2.5 seconds Daniel RK, et al 1988

Body tissue resistance during current flow through the body

Cross section, as well as type, of body tissue, influence body resistance



Lee RC, Dougherty W. Electrical injury: Mechanisms, manifestations, and therapy. IEEE Transactions on Dielectrics and Electrical Insulation 2003;10(5):810-19.

Burn injuries/flash burns – short-circuit/arc accident

Known and possible:

Injury mechanisms after electrical accidents

Direct effects

- Disturbance of the body's own electrical signals (in heart, brain and nerves)
- Temperature increase/elevation (e.g. skin and bones)
- Thrombosis in blood vessels (e.g. to tendons/muscles)
- Nonthermal cell injury, ”electroporation”

Secondary effects

- Oxygen deficiency (Hypoxia)
- Overload of organ (kidney)
- Other (e.g. falls, pulmunary injury)

“How does electricity affect the body?”

Possible acute health effects after electrical accidents

- Cardiac arrest
- Respiratory failure
- Unconsciousness, muscle contractions
- Burn injuries/flash burns, and…
- "Internal burn injuries"
  - muscle injury
  - Kidney damage
- Other (e.g. blood vessels, nerves)
  - Thin nerve fibers for pain, temperature and local autonomic function (sweat, blood flow in the skin) are most vulnerable

Obs. Current path, duration/muscle contractions…

Spring 2017

Guidelines for consulting medical personnel after an electrical power accident/Recommendations based on exposure and acute effects:

After an electrical power accident everyone shall consult medical personnel immediately if they have been:

- exposed to low-voltage electricity with current path through heart/upper body
- exposed to high-voltage electricity
- exposed to lightening injuries

exposure

- unconscious or confused immediately post-accident, or have…
- burn injuries
- signs of nerve damage (such as paresis, balance problem or numbness)

symptoms

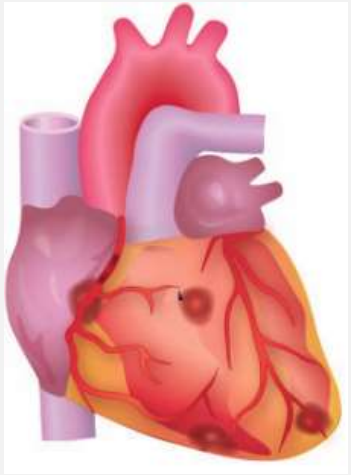
Medical consultation is defined as local MD, acute ward, or medical emergency call/113.

Bedre/ny kunnskap
Bedre tilgang til informasjon
Mer tilgjengelig utstyr

Fokus på innhold mer enn sted

Possible heart disease related to electrical accidents

- Heart attack (ischemic heart disease)
- Arrhythmias
  - Asystolia
  - Ventricular fibrillation
  - Atrial fibrillation
  - Heart Block / branch block



The electrical industry has previously expected 24 hours of monitoring..

Some have suggested 4 hours (Cunningham 1991, Fish 2000).

Many hospitals may take only ECG and discharge patient from hospital (Arrowsmith 1997) …

… BUT - ARRHYTHMIAS HAVE OCCASIONALLY OCCURRED AFTER A LATENCY PERIOD

	Accident	Arrhythmia	Latency	Reference
Female, 20 years	Low voltage	Atrial fibrillation	10 h	Egstrup and Møller, 1983
Male, 43 years	High voltage	Ventricular arrhythmias	12 h	Jensen, 1987
Male, 34 years	Low voltage	Ventricular arrhythmias	12 h	Jensen, 1987
Female, 45 years	Low voltage	Ventricular arrhythmias	8 h	Jensen, 1987

THEREFORE, WE HAVE PREVIOUSLY PROPOSED FOLLOW-UP FOR A MINIMUM OF 12 HOURS - WITH ADJUSTMENT RELATED TO CLINICAL CONDITION

Heart monitoring – What is sufficient?

- Selected patients may be discharged after low voltage injury, if without unconsciousness/syncope, and with normal ECG /no increase in Troponin..

- For others, monitoring in intensive ward for at least 24 h may be warranted.

- A thorough clinical assessment to make sure what current path is, and that there are no possible internal injuries, is critical
  - Clinical examination, ECG, ev. Holter ECG, Echocardiography, sometimes cardiac MRI may be appropriate, depending on the situation

Waldmann V, Narayanan K., et al. Electrical cardiac injuries: Current concepts and management. European Heart Journal Apr 2017. Publisert på vegne av «The European Society of Cardiology»

Case -> Rhabdomyolysis after passage of current from low voltage

- Current Flow 230V hand - hand
- Probably electric current path through the heart region
- No tetanic contractions in hands, presumably freed immediately
- A moment's duration only
- No falls / other trauma
- Recovered in a few minutes
- Notified the colleague, taken to emergency department.

TIDSSKR NOR LEGEFOREN NR. 10, 2018; 138: 930-3

Goffeng LO, Stormoen DR, Veiersted KB. Apprentice electrician with electrical injury. Tidsskr Nor Lægeforen. 2018 doi: 10.4045/tidsskr.17.0613.

Selected health examinations

- Electrocardiogram (ECG) normal and without arrhythmia
- Blood tests 2 h 45 min after the accident
  - Increased S-CK total (37,000 U / L) and S-ALAT
  - Other tests were within the reference range

- Conclusion: Electric current may have caused muscle damage

- Action: Hospitalized and treated with liquid supply (forced diuresis) to prevent kidney damage

Summary - Rhabdomyolysis

- The accident
  - Described as quite undramatic - A moment's duration only
  - CK total: Clearly elevated (37000 U/L, ref. range 50 - 400 U / L)

- Discrepancy between accident and test results
  - Minimizing of a dramatic accident?
  - Can also a minor accident give sign of muscle injury?

- Take blood tests more often even with little suspicion of injury?
  - Result: Hospitalization for necessary preventive treatment

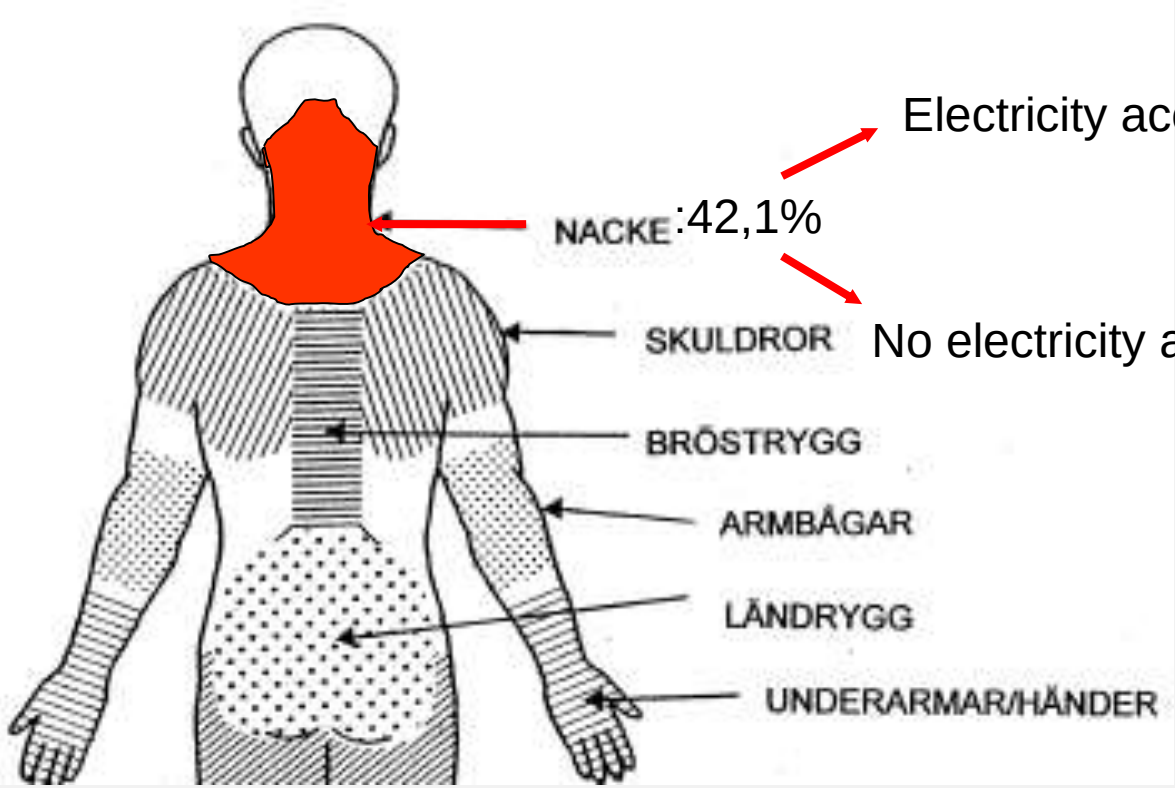
Possible

Delayed sequela of electrical accidents

(that may occur after an asymptomatic period!)

- Musculoskeletal
- Hearing loss
- Nerve injury
- Mental (PTSD)
- Other possible delayed sequela
  - Cardiac arrythmias?
  - Delayed nerve injury (months / years?)?)
  - Cataracts

Muscular pains the previous year among 57 working electricians (%)



NACKE :42,1%

Electricity accidents: → 1990-96: 75,0% → 1960-85: 44,4%

No electricity accidents: → 36,7% → 10,4%

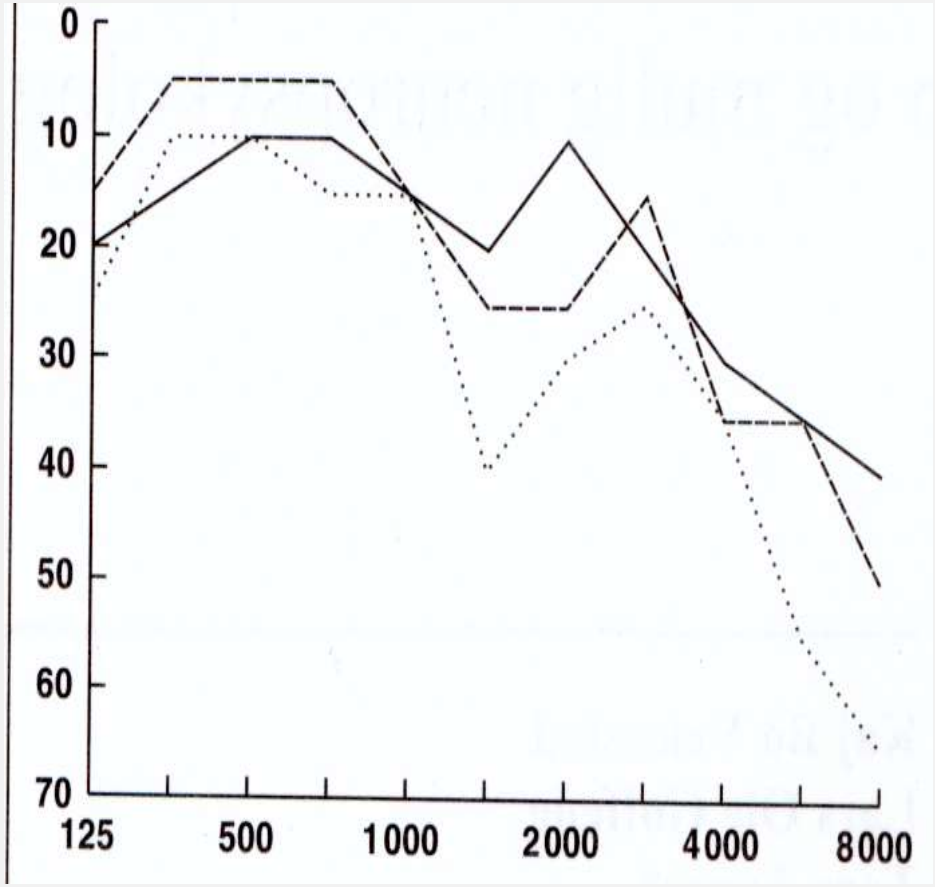
Electrical accidents and muscular pain

"Electric accidents, apparently with no chronic health effect, can increase the frequency of reported muscular pain among otherwise healthy and occupationally active electricians."

Hearing and electrical accidents

Veiersted, Goffeng & Tynes (1997)

- Cases (N=3)
- Age: 28, 52, 61 years.
- Uniform exposure
  - Flow path arm to arm
  - 220 or 340V electrical accidents
  - Duration 1-3 sec.
- Audiometry up to 8KHz.
- Conclusion: Arm to arm electrical accidents can affect hearing frequencies above 3 kHz



Neurological sequela of electrical accidents

(Bailey et al. Neurological…American Journal of Emergency Medicine (2008) 26, 413–418)

Multicenter study in the United States (21 emergency medical units, for a population of approximately 800,000) that year 2000-2004 included 134 patients by risk factors (Table 2)

Table 1 Voltage involved in the electric shock among the 134 patients enrolled in the study

Voltage (V)	No. of patients (%)
Domestic	
120	42 (31)
240	22 (16)
Industrial	
347	20 (15)
460	1 (1)
600	29 (22)
1200	1 (1)
Distribution	
4000	
5000	
14400	
25000	
52000	
DC	
750	
Unknown	

Low voltage 85%

Table 2 Prevalence of the risk factors in the patients enrolled in the study

Factors	n (%)
Transthoracic current	105 (78)
Tetany >1 s	54 (40)
Loss of consciousness	7 (5)
Voltage source ≥1000 V	13 (10)
Humid or wet	22 (16)
Burn marks	77 (57)
Abnormal initial ECG	19 (14)

Neurological sequela of electrical accidents

(Bailey et al. Neurological…American Journal of Emergency Medicine (2008) 26, 413–418)

24 out of 86 had symptoms after 1 year..

Half of these had no complaints at 1st follow-up (median 52 days)

Table 4 Neurologic and neuropsychological symptoms mentioned at the 1-year telephone follow-up [a]

Symptoms	Domestic (n = 36)	Industrial (n = 37)	Distribution (n = 10)	Total [b] (n = 86)
Muscular weakness	1 (3)	5 (14)	1 (10)	8 (9)
Extremity numbness	2 (6)	5 (14)	0	8 (9)
Pain	2 (6)	4 (11)	1 (10)	7 (8)
General weakness—fatigue	3 (8)	1 (3)	1 (10)	6 (7)
Depression	3 (8)	2 (5)	1 (10)	6 (7)
Extremity tingling	2 (6)	3 (8)	0	5 (6)
Memory loss	0	2 (5)	0	2 (2)
Psychological symptoms	0	0	1 (10)	1 (1)
Dizziness	1 (3)	0	0	1 (1)

Values are shown as n (%).

[a] There was no statistical difference in the rate of symptoms according to the voltage category.

[b] Includes unknown voltage and 750 DC.

Emotional reactions

- Death anxiety, rage, relief, apathy acute..
- Fear of working with electricity afterwards
  - Increased respect for electricity, increased vigilance
  - Turns away before opening cabinets
  - Avoids certain tasks, change jobs
- Symptoms
  - Fatigue / sleep problem, energyless
  - Depressed
  - Physical symptoms: Headache, abdominal pain
  - Difficulties coping with problems in everyday life
  - Difficulties making decisions

Kelley et al, 1999

TABLE 1. Relationship between reporting a no-let-go experience and the development of PTSD[a]

	Had no-let-go experience (*N = 32*)	Did not have no-let-go experience (*N = 28*)	Significance (*p* value)
Diagnosed with PTSD (*N/%*)	17 (53%)	7 (25%)	0.025

[a] Thirteen patients did not know whether they had an NLG, mostly due to amnesia for the accident.

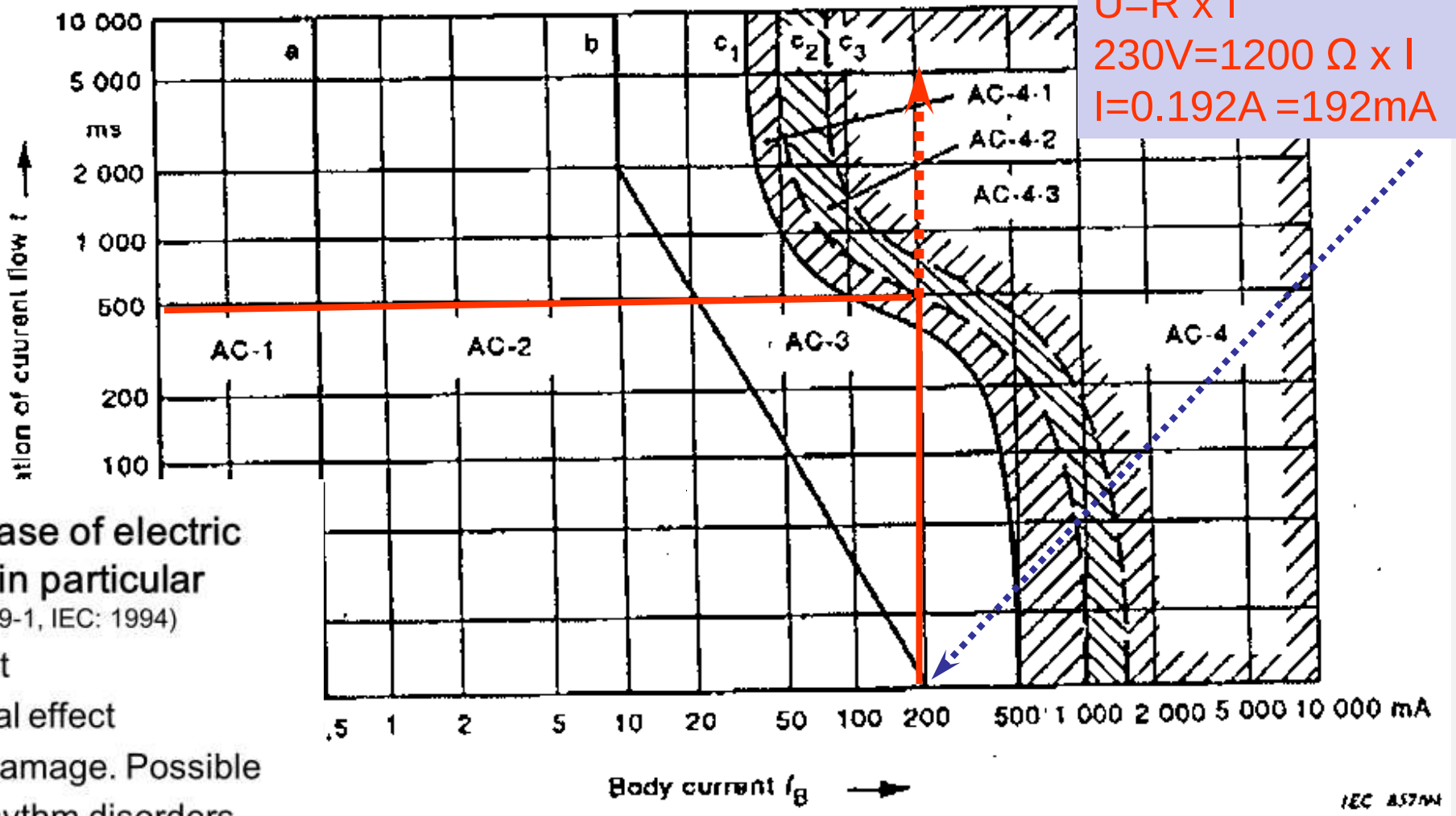
Conclusion: Remember…

- Consider necessity of health consultation or –follow-up after an electrical accident
- Victims are at risk for both acute and delayed health-effects
  - Although most exposures pass without serious injuries, exposure may sometimes also be fatal
- Be open about the exposures or accidents, and learn from them to avoid/prevent future exposures in similar situations

http://www.stami.no/stromskader

STAMI
STATENS ARBEIDSMILJØINSTITUTT

U=R x I
230V=1200 Ω x I
I=0.192A =192mA



STAMI

Hazard zones in case of electric shock, for heart in particular

(see figure 14 from 479-1, IEC: 1994)

AC-1	No physiological effect
AC-2	Mostly no physiological effect
AC-3	Normally no organic damage. Possible muscle cramps and rhythm disorders
AC-4	Rhythm disturbances, "respiratory arrest", burns, "cardiac arrest" otherwise as AC-3

AC-4.1	Ventricular fibrillation	< 5% risk
AC-4.2	-//-	< 50% risk
AC-4.3	-//-	> 50% risk

ventricular fibrillation is initiated within the vulnerable period of the
eeded. Regarding ventricular fibrillation, this graph show effects from
er current paths, heart-current-factor must be considered.

from alternate current (15-100Hz) in persons with current path from left hand to feet.

About acute injury mechanisms …

Duration of exposure

Table 1. Reported thresholds for nerve and muscle injury responses to passage of 60 Hz electric current through body. Electroporation injury threshold pertains to forearm skeletal muscle and nerve tissue exposed to current passing from an electrical contact point in the hand.

Electrophysiological Response	Threshold Current*
Sensation of pain (Fingertip)	1.0 mA (M†) 0.5 mA (F)
"No-Let-Go": involuntary contraction of forearm muscles	16 mA (M) 11 mA (F)
Cardiac: Arrhythmia Ventricular Fibrillation	60 mA 100 mA
Electroporation of Forearm Muscle (hand contact)	1,500 mA

*Assumes current path in the upper extremity.
†(M)–Males; (F)–Females

Lee and Dougherty, 2003

Skin resistance and exposure duration

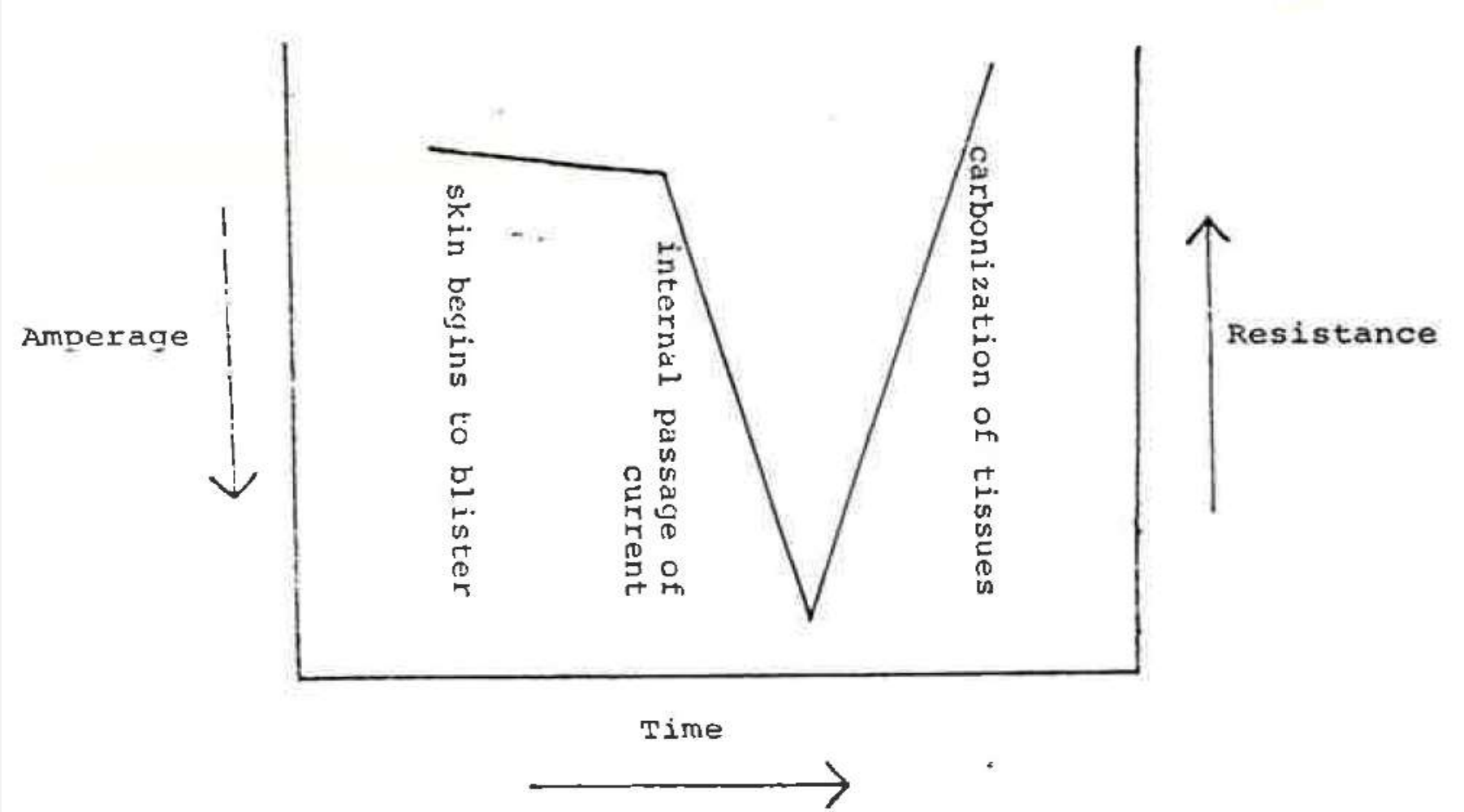
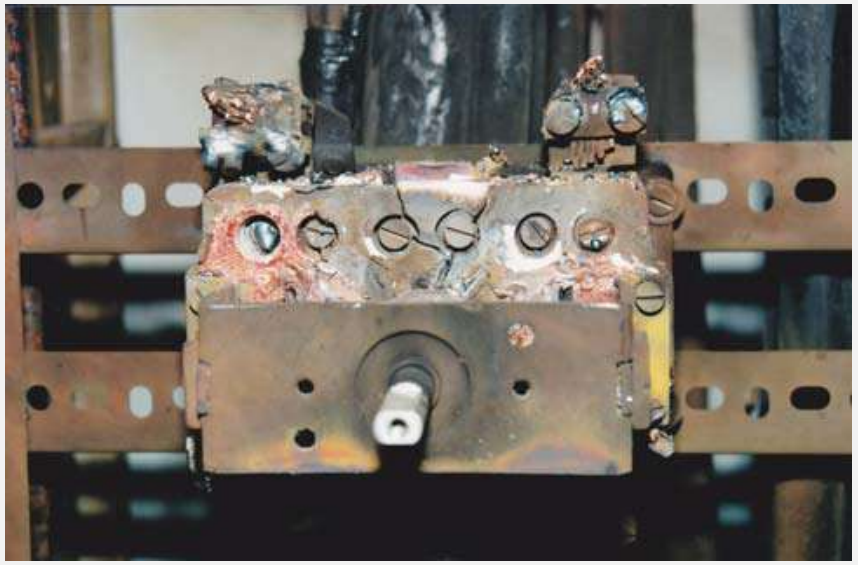


Figure 1. The relationship of amperage and resistance to current flow is schematically depicted.

Cooper M A. Electrical and Lightning Injuries» Emerg Med Clin North Am 1984; 2(3):489-501.

Burn injuries/flash burns – short-circuit/arc accident



Vinstri handleggur

Hægri handleggur

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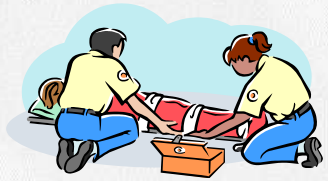
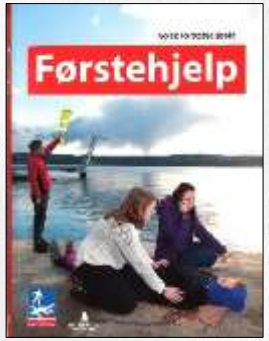
Electrician/ victim

Colleagues /first-aid

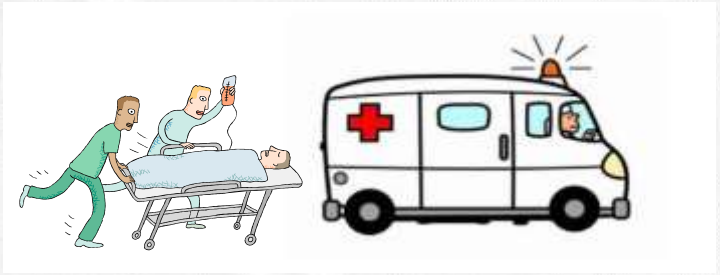




Emergency-call staff/ handbook

Medisinsk Nødtelefon

Ambulance staff/ guidelines



Hospital/ procedures

Oppfylles minst et av kriteriene under skal forulykkede til sykehus umiddelbart etter nødvendig førstehjelp:

- Har vært utsatt for høyspent
- Har vært utsatt for lynnedslag
- Har vært utsatt for lavspent strømgjennomgang med sannsynlig strømvei gjennom kroppen
- Har vært bevisstløs eller omtåket rett etter ulykken
- Har brannskader
- Har tegn på nerveskader (for eksempel lammelser)

Guidelines for consulting medical personnel (2017)

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Medical treatment and follow-up - What was new in 2017/18?

Heart

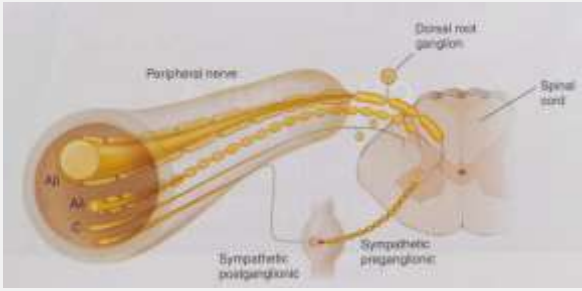
- Cardiac Monitoring (2017) - Justifies heart regime

Muscle injury

- Rhabdomyolysis (2018) - Pay attention!

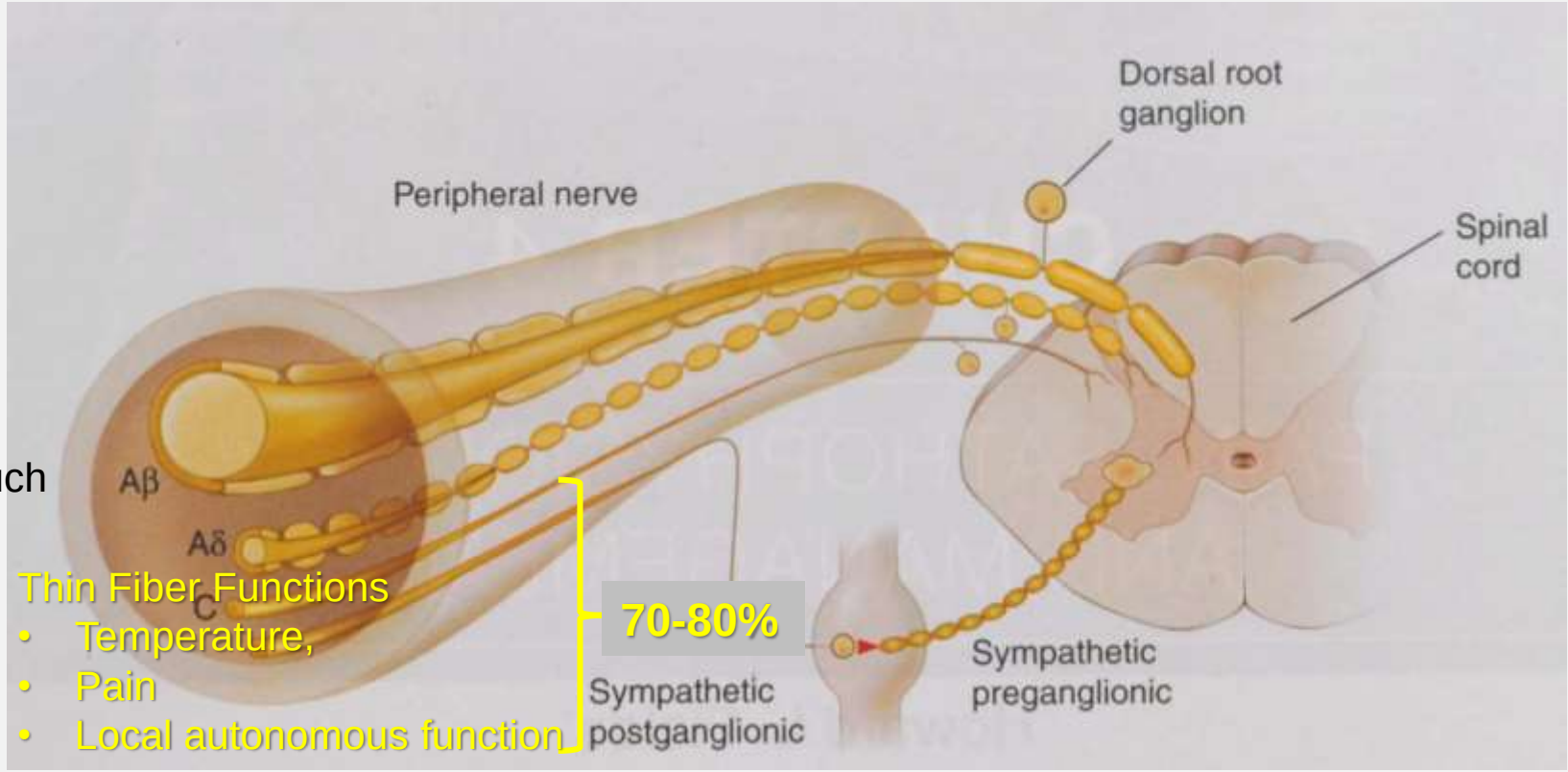
Nerve injury

- Nervous Injuries (2017) - Extends examinations



Nervous system effects - Thin fiber neuropathy

Thin nerve fibers for pain, temperature and local autonomic function (sweat, blood flow in the skin) are most vulnerable



Tondel M, Blomqvist A, Jakobsson K, Perssson B, Thomée S, Gunnarsson L-G (2017) Elolyckor kan ge skador som visar sig efter lång tid – det akuta omhändertagandet kan vara avgörande på sikt. Läkartidningen 2017;114:110-113 (In Swedish)