EVALUATING THERMAL AND VIBRATIONAL IMPACTS OF EXTRICATION TOOLS IN LARGE OBJECT IMPALEMENT RESCUE

Nic Ionmhain Ú [1,2,3], Kirwan P [1,4], Vio G[5], Fogg T [1,6]

[1]Careflight, [2] Liverpool Hospital, [3] University of New South Wales, [4]Fire and Rescue NSW, [5] University of Sydney, [6] North Shore Hospital,

A hypothesis generating case







https://www.news.com.au/national/nsw-act/metal-rod-impales-young-mans-forehead-at-construction-site/news-story/0d7d4a0625ea164852ccaf73d23a4c79
https://www.smh.com.au/national/nsw/impaled-teens-fight-to-recover-20130817-2s3gf.html

Introduction

- Impalement is an uncommon heterogenous clinical scenario
- “Leave the object in situ” has limitations
- Evidence Gap (literature and local databases)
- The impalment extrication dilemma: Clinical urgency versus causing further injury
  - Not discussed in the more recent UK extrication guidelines (MVC)
- General approach considers: Patient factors / Object factors / Tools available / Environment / Operator factors

Measures that are generally considered in extrication

- Test cuts
- Manual stabilisation of patient and object
- Safety planning: heat / sparks / oxygen management / debris with mitigation including PPE & water pouring
- Minimal shortening

Physics of cutting: How energy might transfer

- Vibration:
  - *Periodic mechanical oscillation / repetitive motion in object over time (measured as acceleration m/s^2 or G force)*
- Resonant frequency:
  - *The natural frequency a system will oscillate with maximum amplified displacement when excited by an external force*
- Damping
  - *Restraint of vibratory motion by dissipation of energy (structural / viscoelastic / internal)*
- Torque
  - *Rotational force applied around an axis creating twist at the point of material failure*
- Temperature & energy transfer
  - *A measure of average kinetic energy of a system*
  - *Radiation / Convection / Conduction / Evaporation*
  - *Thermal buffering*

Vibration in pre-hospital and retrieval medicine

- Ambulance (0-2Hz)
- Rotary wing (main rotor 12-15 Hz and tail rotor 23-25 Hz)
- Fixed wing (turbulence 0-4Hz)
  - All are minimised as part of design function of platform

- Some clinical consequences
  - Relate to resonant frequency but tissue does not exist in isolation
  - Other effects e.g. nausea / metabolic rate / pain fatigue / muscle contraction/ clot displacement / BP variation

Table 2.1 Effects of vibration according to its frequency.

Frequency (Hz)	Effect
0–2	Motion sickness
3–4	Hyperventilation (caused by resonance of air in trachea)
3–8	Abdominal contents
4–8	Leg muscles
12–15	Differential head/torso movement
15–20	Soft facial muscles
60–90	Eyes
20–100	Muscle contraction

Low, A., & Hulme, J. (Eds.). (2015). ABC of transfer and retrieval medicine. Wiley Blackwell.

Table 1: Natural frequencies of the human body.

Body Part	Natural Frequency (Hz)
Trunk	3-6
Eyeball	20-25
Chest	4-6
Thorax	3
Spine	3-5
Heart	4-5
Shoulders	2-6
Head	30
Stomach	4-7
Colon	20-25

T.M. Farid, A. Salah, W. Abbas, "Design of optimal linear suspension for quarter car with human model using genetic algorithms", Journal of Applied Sciences Research, 7(11), 1709-1720, 2011.

Aims

- Pilot study to quantify heat transfer and vibration induced by common extrication tools when cutting objects that are commonly associated with impalement.

- Provide some pragmatic evidence base suggestions for operators on scene

Experiment

Methods: Materials





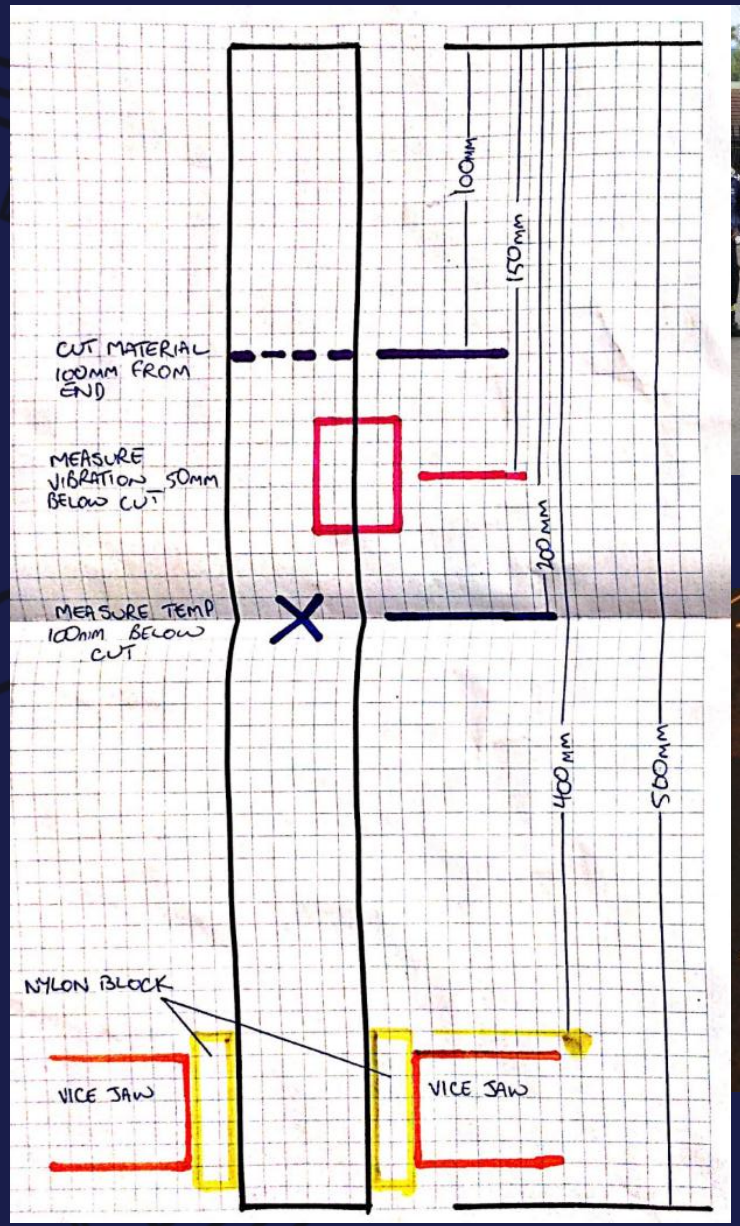
Tools

Tools	Mode of action
Ultra Thermic Lance	Thermal cutting
Reciprocating Saw	Reciprocating (back and forth) motion
Power Saw	Large (305mm) rotating abrasive disc
Hand(hack) Saw	Manual reciprocating motion
Hydraulic Rescue Shears	Bypass cutting action (like scissors)
Angle Grinder	Small (100mmx1mm) rotating abrasive disc

Materials

Object	Physical properties
Wooden dowel	35mm clear (no knots) pine
Reinforcing Bar	Mild steel (16mm diameter) irregular surface
Star picket	Non-equal, 3 rib, mild steel
Fencing Post	25mm hollow square section, steel

Temperature measurements via infrared thermometer and thermal imaging camera













Methods: Experiment set up for vibration and temperature

- X 5 cuts performed with each individual tool on the same object
- Temperature measured utilising star pickets and infrared and thermal imaging camera on a different day
- Vibration was measured with an accelerometer 50mm below the cut (250mm from the point of fixation)
- Temperature was measured 100mm below the cut (200mm from the point of fixation)

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Results

Results – Vibration: some examples

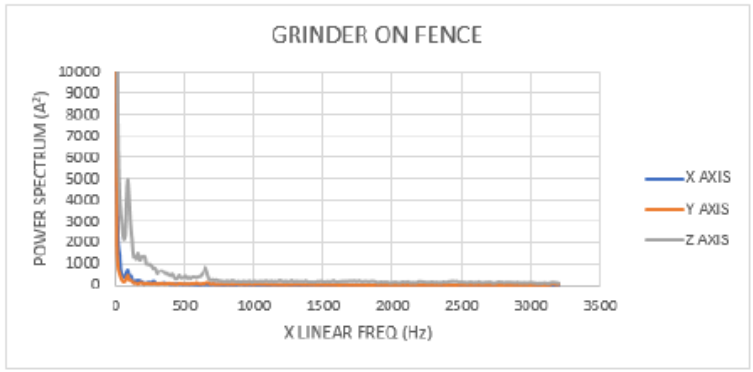


Figure 24 - Vibration vs Frequency for Angle Grinder on Fencing Post - Zoomed

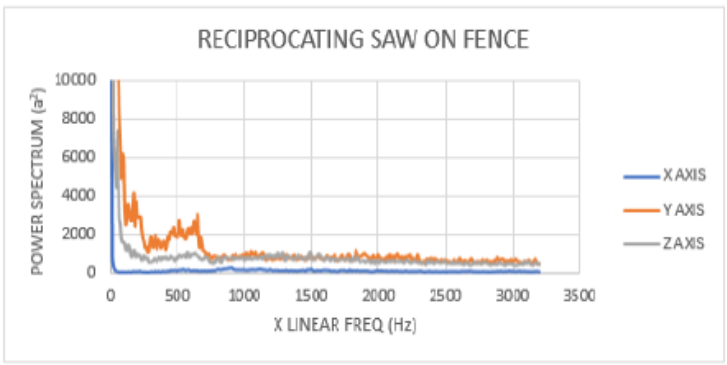


Figure 28 - Vibration vs Frequency for Reciprocating Saw on Fencing Post

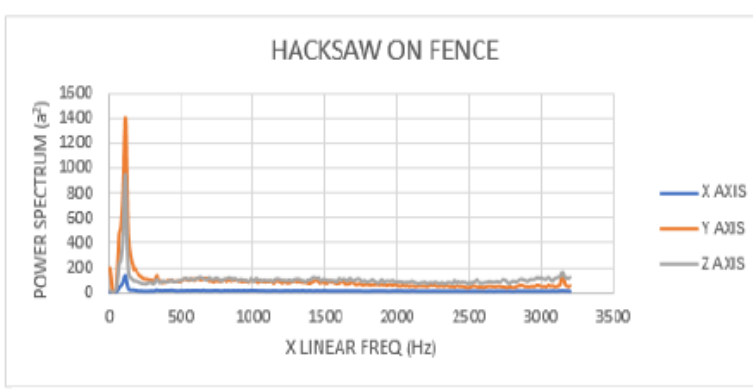


Figure 30 - Vibration vs Frequency for Hacksaw on Fencing Post

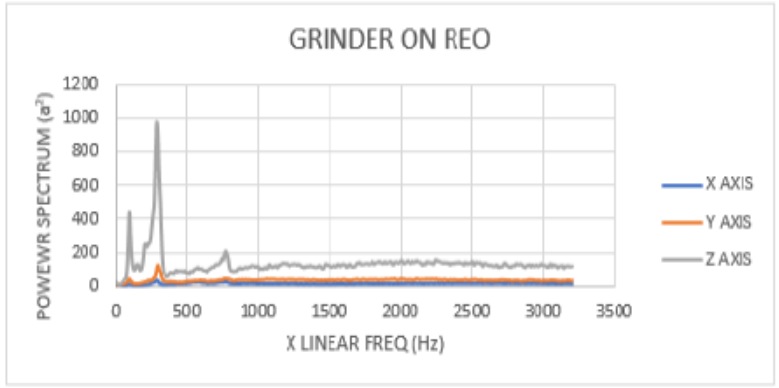


Figure 25 - Vibration vs Frequency for Angle Grinder on Reinforcing Bar

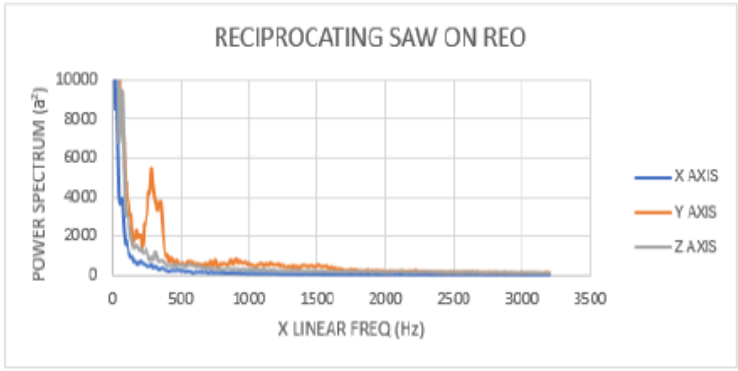


Figure 29 - Vibration vs Frequency for Reciprocating Saw on Reinforcing Bar

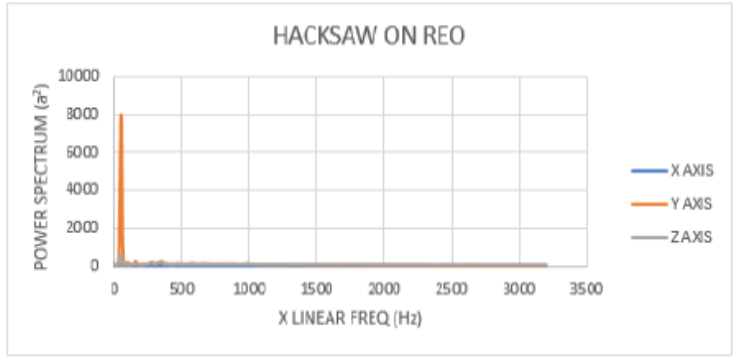
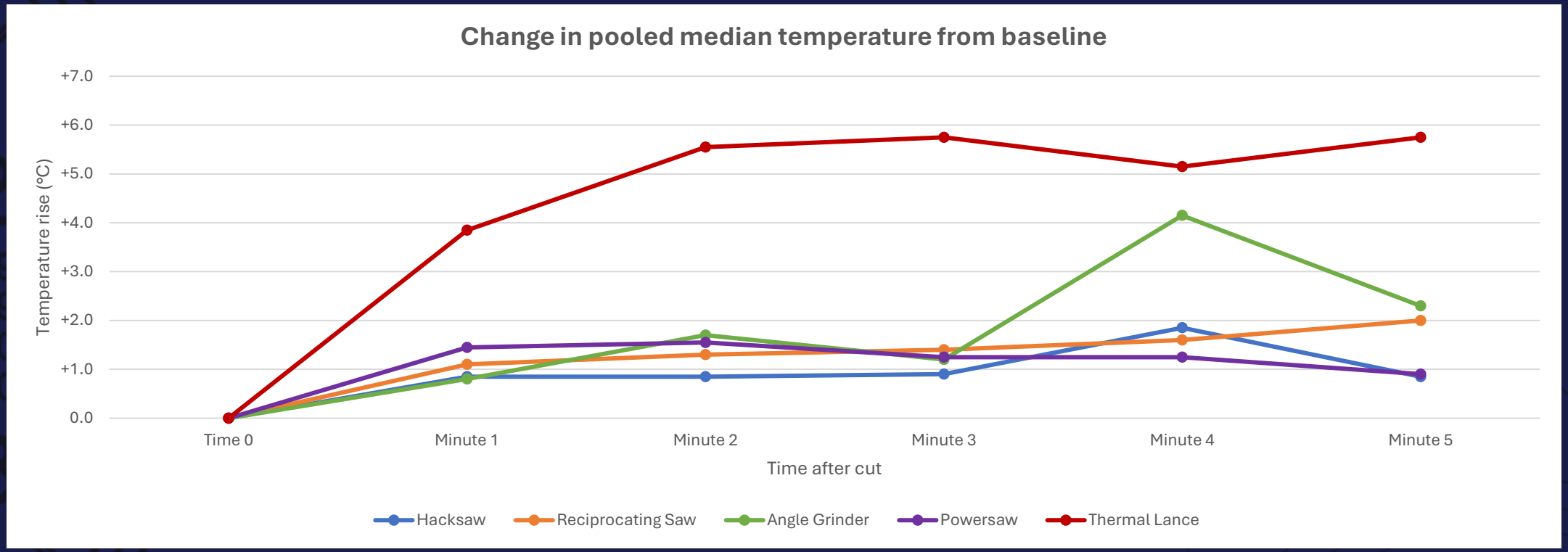


Figure 31 - Vibration vs Frequency for Hacksaw on Reinforcing Bar

- *No vibration with the thermal lance or hydraulic shears*
- *Most tools generated signal at around 100/300/500Hz with the hacksaw demonstrating lower frequency signal*
- *0 Hz spike is an artefact on the graph*
- *The powersaw produced similar graphs with higher peak acceleration*

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Results: Temperature to star picket over 5 minutes



- *Measured using an infrared thermometer and thermal imaging camera*
- *All cuts done on* ***star pickets.*** *Temperature measured 100mm from cut*
- *The hydraulic shears were omitted in this section of study*
- *Thermal-lance cut 4 reached ~52°C on both instruments. The median curve does not show this individual peak.*

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Discussion

- Lab based pilot study with significant limitations
- No vibration of note was measured with: Thermal lance (did not cut wood well) or Hydraulic shears (large lateral force and torque)
- There were high frequency responses noted in response to the: Powersaw / Angle Grinder / Reciprocating saw
  - These are higher than resonant frequency however this does not account for harmonic frequencies
- Visually the biggest displacement is hacksaw which also had a lower frequency which relates to the operator cutting
- The powersaw had the highest peak acceleration (which could provide more force)

Discussion: Consequences of findings

- Vibration:
  - Risk of matching resonant frequency resulting in shear force to tissues is likely to be low in this clinical scenario
  - These measurements were taken in a cantilever set up so theoretically there would be less vibration in a clinical scenario (due to damping)
  - The vibration induced by an extrication tool is probably not as high a risk as perceived.
- Thermal findings:
  - Heat generation not as significant as expected when cutting star pickets
  - Do we need to do cool water irrigation during cutting?
- What about speed?
- What does that mean for clinicians?

Suggested approach on this basis

A time out with shared decision making

Asking the right questions – Clinical urgency / Properties of the object / Environment / Time required/ Team skill mix and equipment

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Extrication tools: pros and cons

Tool / mass	Cut time *	Vibration findings	Temperature (°C) Δ median / max (start)	Pros	Cons / operational constraints
Thermal lance 2 kg handpiece	Seconds	No vibration reported	+5.75 / 52 (31–37) Cut 4: IR 51.6°C; camera 52°C	Rapid cutting Broad material capability*	Set-up time, limited availability and expense Training, consumable rods and oxygen costs Unsuitable for timber in this study and some metals (brass/bronze) Ejects molten metal; rod shortens during cutting, spark risk
Reciprocating saw 4 kg	**R:** 5.16 s **SP:** 4.76 s	Peaks: ~500 Hz fence; ~300 Hz rebar	+2.00 / 36 (28–31.4) 3 cuts	Quick set up time Fits under a patient Relatively compact, thin blade Material-specific blades available	Blade may catch or bite Blade must match the material
Power saw 11.5 kg	Estimated around 10-15s	High-frequency response; no single peak tabulated	+1.55 / 40 (32–37)	Cuts hard materials	Sparks, heat, noise and motor exhaust Large tool Disc wear can reduce cutting depth
Hand (hack)saw 0.75 kg	**R:** 44.64 s **SP:** 44.49 s (influenced by fatigue)	Peak around 50 Hz	+1.85 / 32 (24–31)	Low cost, small size, fine teeth	Less suitable for hard or thick materials Manual operation Slow
Hydraulic rescue shears 15 kg	Instantaneous	No vibration reported; twisting observed	Not measured	Quick and quiet Battery-powered options available	Bulky and heavy May twist the impaled object – lateral force
Angle grinder 2 kg	**R:** 17.60 s **SP:** 19.82 s	Fence: ~100 Hz Rebar: ~100, 300, 750 Hz	+4.15 / 30 (20–29)	Small and manoeuvrable	Sparks and noise Limited cutting depth Might need to move around the object and cut from more than one direction

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- *Outside the experiment; similar-sized R (rebar) and SP (aluminium star picket). Recip saw used a newer blade.
- Times will be influenced by the size of object / set up time / orientation of the patient / operator fatigue

Limitations

- Model
  - Materials were clamped in a rigid vice rather than human tissue which has different damping / vibrational properties
  - Tissue level damage was not studied
  - Single model assumption
- Sensors / Measurements
  - Unmeasured forces (e.g. torque / mechanical impulse / direct force /kick back / blade catch / hand, arm vibration impact on the operator)
  - Accuracy of the thermometers used
  - Displacement was not measured though we could integrate our findings to obtain this
- Materials
  - Limited number of materials / cuts / fixed sizes
  - Temperature measurements only done on star pickets
- Operator: extremely experienced

Future directions

- Repeat experiments on cadaveric porcine models for real world fixation and damping
- Further computational models
- Assess impact on operator
- Compare a novice versus a skilled operator
- Different models of impalement instead of a through and through

Conclusion and implications

- A clinically uncommon scenario with a heterogenous cohort of patients, environment and operators
- There is not a large amount of evidence available for the perceived risks
  - From our data there does not appear to be a significant risk of thermal transfer
  - There was not significant cross over with resonant frequency within this lab based model
- Shared discussion and pros and cons and applying to the scenario
- Changing rescue training and clinician training to incorporate a time out to chose the best approach for the individual case

Questions?

Acknowledgements

- Justin Forth
- Dr. Adam Osmanski

- Fencing was donated by Playsafe Fencing Pty Ltd from off cuts and has no commercial value
- Fire & Rescue New South Wales purchased star pickets, timber dowel, reinforcing bar, all blades, discs and other consumables
-

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