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Strain Energy Absorption Corresponds to Decreased Incidence of Ventricular Fibrillation in a Commotio Cordis Model

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Strain Energy Absorption Corresponds to Decreased Incidence of Ventricular Fibrillation in a Commotio Cordis Model

Abstract

A healthy teenage boy is playing high school baseball, when he is struck in the chest by the ball; minutes later, his heart is experiencing ventricular fibrillation (VF) and the only way to resuscitate him is to use a defibrillator. This phenomenon, is known as Commotio Cordis (CC), and occurs as many as 20 times each year in the United States. CC most frequently occurs in sports with small balls (e.g. baseball or lacrosse) and requires a specific set of circumstances–a projectile with a certain amount of energy that impacts directly over the left ventricle of the heart during a ~15ms window during the upstroke of the heartbeat's T-wave. While it might seem that commercially available chest protectors would prevent CC, the sad reality is that they don't – 20% of recorded cases have been wearing chest protectors, and studies using a porcine animal model have shown that none of the protectors tested significantly reduced the incidence of VF [1]. There is a need to determine protector materials that might prevent CC from occurring. The goal of this study is to determine whether the energy absorption of potential protector materials correlates with the occurrence of VF in a porcine model.

Keywords

energy, ventricular fibrillation, commotio cordis, chest protector

Disciplines

Biomechanical Engineering

Comments

Poster presented at the American Society of Biomechanics Annual Meeting, held at the Raleigh Convention Center in Raleigh, North Carolina, from August 2-5, 2016.

This conference presentation is available at Dordt Digital Collections: https://digitalcollections.dordt.edu/faculty_work/571

Can Chest Protectors Increase Survival in Commotio Cordis?

Strain Energy Absorption Corresponds To Decreased Incidence Of Ventricular Fibrillation

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Introduction

What is Commotio Cordis (CC) & How common is it?

- CC is death after a sudden chest wall impact with no structural damage (lacerations, broken ribs, etc.)
- CC occurs 15-20 times annually in the United States
- Historically victims are 96% male and 80% and <18 years old

What causes CC?

CC occurs when an impact meets all of the following (Fig 1):

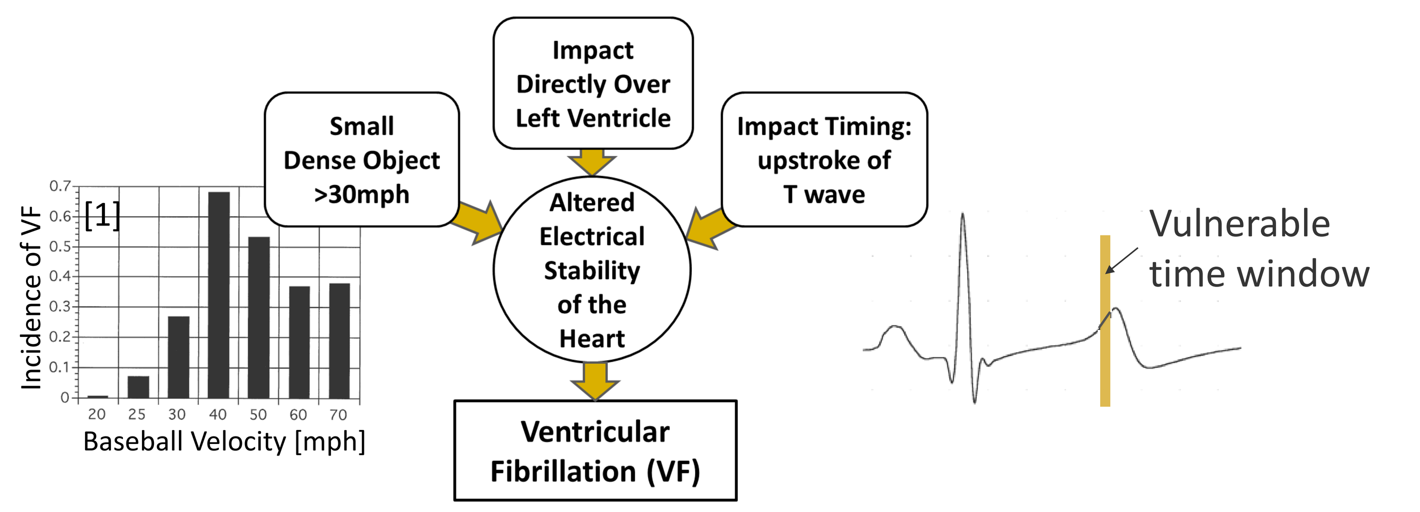

Figure 1: The combination of factors that lead to VF in a CC model

Would it help if athletes wore chest protectors?

- 20% of victims of recorded victims wore chest protectors
- 0 of 12 commercial chest protectors significantly decreased VF occurrence in a porcine model [2]

What are you doing about it?

We hypothesize that a material's energy absorption properties decrease the occurrence of VF in a porcine model.

Methods

Chest Barrier Materials

A 6mm thick dense foam barrier was tested: (Fig 2):

1. Alone
2. + laminate
3. + laminate & 6mm memory foam
4. + laminate & 8mm memory foam

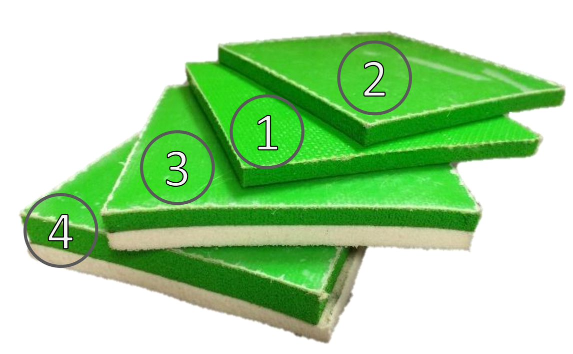

Figure 2: Barrier Materials

Animal Testing

Juvenile male swine were prepared and tested using the setup in Fig 3 and the standard procedure described by Link et al [3]. Briefly:

- lacrosse ball impact
  - ✓ 40mph
  - ✓ directly over the left ventricle
  - ✓ during the vulnerable portion of the cardiac cycle
- Repeat impacts were delivered if vital signs returned to pre-impact baseline
- Chest barrier materials were placed directly over the left ventricle prior to impact
- Control tests used no barrier material
- Impacts were given in a random order

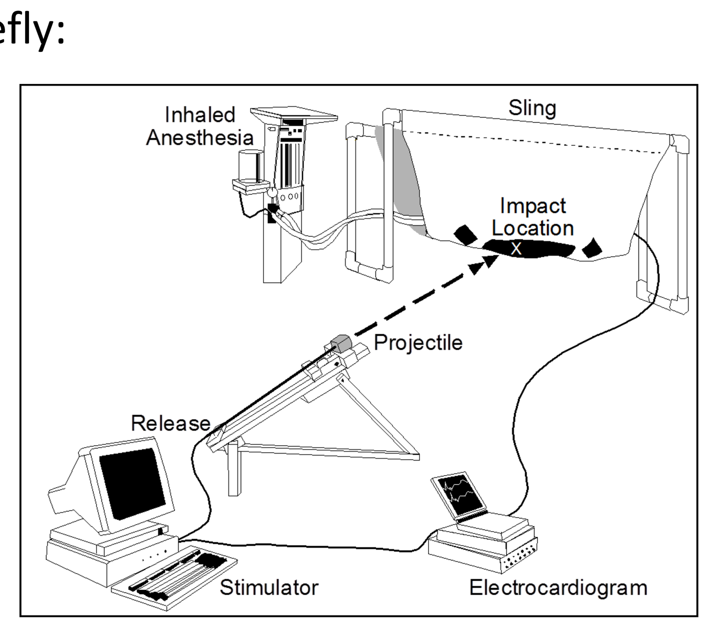

Figure 3: Animal Testing Setup

Material Testing

Quasi-static loading according to ASTM standards for cellular plastics

- Materials placed between flat plates and compressed at 60mm/min to a peak force of 360N (equivalent to a 40mph impact by a lacrosse ball [4])
- Calculated stress and strain from recorded force & displacement
- Calculated energy absorption efficiency for each material
- Compared quasi-static peak efficiency with occurrence of VF during animal tests

References

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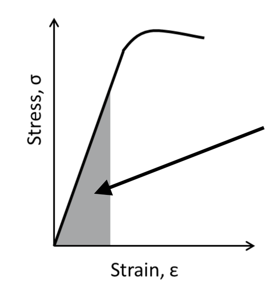
Energy Absorption Efficiency

- Strain energy density is the area under the stress-strain curve



$$\text{Strain Energy Density} = \int_0^e \sigma(\varepsilon)d\varepsilon$$

Units Check Out:

$$Pa = \frac{N}{m^2} = \frac{N \cdot m}{m^2 \cdot m} = \frac{J}{m^3}$$

- Energy absorption efficiency characterizes a materials ability to absorb stress as it compresses by normalizing the energy absorbed by the stress applied:

$$E = \frac{\int_0^e \sigma(\epsilon)d\epsilon}{\sigma}$$

Results

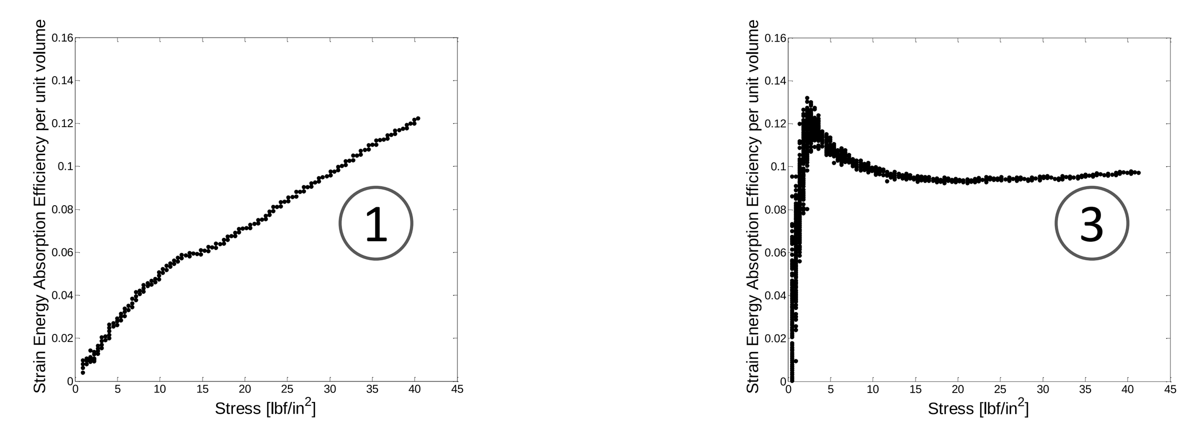


Figure 4: Strain Energy Efficiency curves for materials 1 & 3. Notice the shape contrast between the hard foam only (steadily increasing trend) vs the soft-hard combination (rapid peak followed by a plateau).

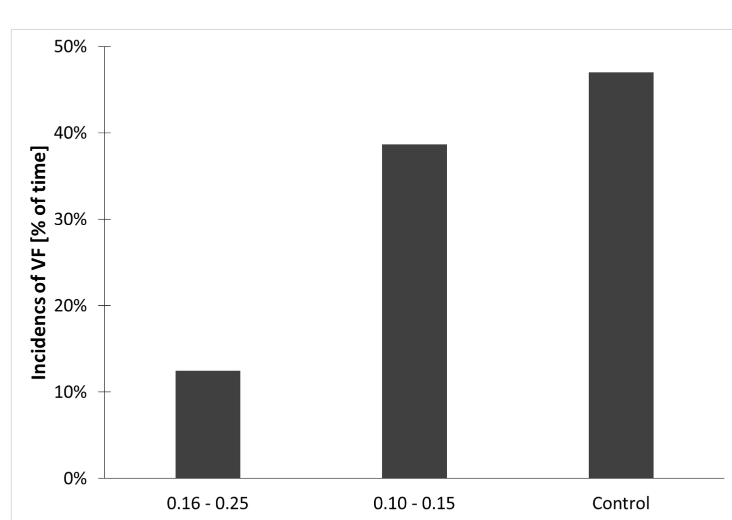


Figure 5: Animals wearing barriers with a higher % peak energy efficiency experienced fewer instances of VF

Discussion & Conclusion

Why look at energy characteristics instead of stiffness?

- We tried that and it didn't work
- The most successful material failure theories are energy-based (e.g. von mises failure theory)
- Energy efficiency allows us to observe a material's energy absorption characteristics during an impact
- Mechanical systems can be tuned to avoid particular energy states (resonance); possibly chest barriers could be also

What is your most interesting finding?

- For these materials, a higher peak energy absorption efficiency corresponds to a decreased occurrence of VF (Fig. 5).

What is your current challenge?

- How to measure the frequency response of the chest wall in a living creature. Any ideas?

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