DO MECHANICAL PROPERTIES OF CHEST PROTECTORS CORRELATE WITH THE INCIDENCE OF VENTRICULAR FIBRILLATION IN A SUDDEN DEATH (COMMOTIO CORDIS) SWINE MODEL?

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INTRODUCTION

For young healthy athletes, Commotio cordis is the second leading cause of death is commotio cordis. Commotio cordis (CC) is the sudden death (or aborted sudden death) due to a non-penetrating chest wall impact that, in the absence of injury to the ribs, sternum and heart, occurs in a vulnerable window on the T-wave of the cardiac cycle (10 to 30 ms prior to the T-peak) and results in ventricle fibrillation (VF). The fatal impact mostly occurs to the left chest wall in the region of the cardiac silhouette by a projectile (ball or puck) traveling at speeds consistent with youth play. Despite increases in the use of protective gear, to date, 7 young athletes (3 lacrosse goalies, 2 baseball catchers, and 2 hockey goalies), all wearing chest protectors, have died from commotio cordis [1].

We hypothesized that the efficacy of chest protectors could be predicted from quasi-static compression testing. The purpose of this study was to determine if a correlation existed between the incidence of VF [2] and three quasi-static mechanical properties, displacement, stiffness, and pressure distribution, for various baseball and lacrosse chest protectors.

METHODS

Quasi-static compression testing was performed on eleven models of lacrosse and baseball chest protectors evaluated in a previous animal model of CC [2]. Each model was placed on a rigid plate and a compressive load was applied by a rigid spherical object positioned on each chest protector using a servo hydraulic material tester (Instron Corp., Canton, MA). The spherical object was a hardwood ball with a diameter of 6.35 cm and 7.62 cm for the lacrosse and baseball chest protectors, respectively. A preload of 10 N was applied and then cycled up to 6000 N five times at 1 Hz. Load and actuator position data were collected at 100 Hz.

During the quasi-static compression testing, displacement, stiffness, and pressure distribution were measured. Displacement was defined as the difference from the minimally and maximally compressed positions of each model. Stiffness was calculated from load-displacement measurements, first for the region of low stiffness between 0 and 400 N and second for the region of high stiffness between 2400 and 5000 N. A pressure sensitive film (Ultra Super Low Fuji Film, Fuji Photo, Co., Ltd., Tokyo, Japan) was used to measure the distribution of applied pressure.

Linear regression (SigmaStat3.1, Systat, Point Richmond, CA) was used to examine correlations between these mechanical properties and the incidence of VF, which was determined for the same chest protector models in a previous animal model [2]. We computed the R^2 and P values for the regression equation. A significance value of $P < 0.05$ was set *a priori*.

RESULTS AND DISCUSSION

The displacement of each model ranged from 7.09 to 21.03 mm. There was a trend of increasing displacement with decreasing incidence of VF, but no significant linear correlation was found ($R^2 = 0.14$, $P = 0.06$).

The compression testing revealed a highly nonlinear load-displacement behavior in all chest protector models. There was an initial range of very low stiffness (10.88 to 48.24 N/mm), then a transition region, followed by a region of high stiffness (2425.42 to 7335.44 N/mm) that was assumed to be associated with the bottoming out of the chest protector. Neither the low stiffness region ($R^2 = 0.1$, $P = 0.12$) nor the high stiffness region ($R^2 = 0.05$, $P = 0.25$) demonstrated a linear correlation with the occurrence of VF.

The area of the pressure distribution ranged in shape from circular to rectangular. Grouping all models together, we found that there was a significant ($P = 0.01$) decrease in the incidence of VF as the area of the pressure distribution increased.

This study was performed to determine if quasi-static compression testing could explain the variance in the incidence of VF. While none of the models significantly increased or decreased the risk of VF in the previous study [2], we did find that the incidence of VF significantly decreased as the pressure distribution increased. While this finding seems logical and intuitive, it is still surprising considering the complexity and the dynamic nature of CC.

CONCLUSIONS

The goal of this experiment was to develop an experimental protocol that could be incorporated into performance standard test protocols for chest protectors to ensure that all models meet a minimal standard performance requirement. Surprisingly, we found that increases in quasi-static pressure distribution were associated with a significant decrease in the incidence of VF. It remains to be demonstrated that chest protectors constructed using these findings as design criteria can significantly reduce the incidence of VF.

REFERENCES

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