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A System for the Measurement of Laceration Potential

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INTRODUCTION

Soft tissue injuries occur in 92% of frontal impacts where car drivers wearing seat belts strike their heads against steering wheels. Of these injuries, 57% are single facial injuries [1]. While the anthropomorphic dummies used in crash testing have greatly improved over the years, current methods for measuring facial laceration rely on a chamois covering fastened around the head [2]. The chamois head covering has many deficiencies: each chamois has a different thicknesses (a single chamois can vary from 0.5 to 3.0 mm in thickness); impact response is inconsistent; a chamois moves during impact, altering its dynamic impact response; and when stretched taut it is stressed at critical points.

A project was undertaken at Triangle Research and Development Corporation (TRDC) to design better ways of understanding the mechanics of laceration injuries. In this project, a new kind of face mask to measure and predict facial laceration potential was designed, developed to prototype, and tested. The work was sponsored by the U.S. Department of Transportation under Phase I and Phase II Small Business Innovative Research (SBIR) contracts [3]. The Phase II contract was awarded to continue development of a complete laceration measurement system. The system will employ an automated camera to quantify the extent of damage to the face mask.

The data from such a system could improve seat belt and air bag technology and enhance the design of steering wheels, dashboards, and windshields. As the quantity of injury research data grows, it becomes critical that accurate, reproducible methods of measuring laceration potential be developed. A reasonably priced, easily procured face mask of consistent quality will be useful in trauma and injury research and component testing.

The prototype face mask was designed for the head of a male Hybrid III manikin head, which is currently favored for research by automobile makers, insurance carriers, DOT, and other government agencies and institutions. The mask is made of an "artificial skin" that mimics the laceration characteristics of living human skin, causes minimal dynamic impact response changes, and should be suited to measure facial laceration during specific trauma research and automotive component tests. Unlike chamois, the skin can be manufactured consistently, allowing research results to be accurately repeated. The mask is designed to give roughly the same Triplex Laceration Index scores as double-layer chamois.

TESTING EQUIPMENT AND PROTOCOL

Drop tests were conducted to provide a basis to compare the laceration characteristics of the new mask materials with those of human skin and chamois. The protocol was designed to insure consistency with the research conducted at Peugeot-Renault and the University of Birmingham (UB), U.K. [4-6]. Nine threaded impactors were fabricated, three each from 15mm, 20mm and 25mm aluminum stock. The stock was cut on one end so that each set of impactors contained a 30-, 60-, and 90-degree angle at the impact point. The resulting cutting edges were approximately 10-microns wide. The edges were sharpened as necessary during testing.

A 412.5-gram weight was prepared from a cylinder of solid plastic stock. One end of the weight was threaded to allow attachment of the impactors and the other end was threaded to receive an accelerometer.

The impactor was guided by a length of PVC pipe. The pipe had several holes drilled through it to allow the insertion of a locating pin. The pin allowed changes to be made in the drop height and therefore in the total force of the impact. The acceleration-time history from the accelerometer was collected using a high-speed, PC-based data acquisition system at a rate of 4000 Hz. Each specimen was mounted on a pine block. Harder woods were tried, but pine most accurately duplicated the UB results. The pine block was mounted on a metal table placed beneath the drop pipe.

The test bed used for the drop tests permitted the collection of data that plotted cut depth against peak force generated per unit edge length. Each of the 39 specimens developed were subjected to the same impactor tests and the results compared to both human skin data and chamois data. Some samples that obviously fell outside the acceptable range were eliminated after minimal testing. Materials that seemed to better mimic the skin/chamois results underwent as many as 18 drop tests. More than 200 individual tests were performed at TRDC on the synthetic materials. The result from each test helped guide the decisions regarding formulation of the next synthetic skin.

FACE MASK MATERIALS AND MOLDING

Several artificial skin composites using thermoset silicone and polyurethane compounds with various woven mats, threads, and other fillers were fabricated. Each specimen was tested, and the test results of individual specimens were used to help determine the elastomer formulation, the choice of polymer for impregnation, the filler material, cure temperature, and cure time for the next specimen. Thirty-nine different specimens were fabricated.

At the end of the effort, a modified two-part thermoset silicone was found to exhibit the best potential for fabricating a face mask for measuring laceration potential. The synthetic skin will continue to be modified as research proceeds.

The mold for the mask was developed from the male Hybrid III head using specialized molding techniques developed by TRDC and APM, Inc., a local manufacturer of medical training devices. The four-part mold prepared for injection molding of the prototype face mask was fabricated. The surfaces of the mold were polished, waxed, and treated with a mold release.

Two face masks were molded using the selected thermoset compounds. The mold was preheated to about 42°C and the thermoset was blended according to procedures and formulas developed when the material was selected. This viscous material was pressure-injected into the mold. After the material was cured, the mold was opened and the face mask removed.

AUTOMATED MEASUREMENT SYSTEM

A machine vision system is currently under development to automate and quantify the process of determining the extent of laceration damage to the mask. Essentially, a mask would be mounted on a wire or clear plastic head frame. A solid state camera would be positioned a fixed distance from the headform. The headform will be mounted on a pivot so that the head can be rotated, thereby permitting several camera viewing angles. The camera vision system would then determine the number and length of each laceration to calculate measures such as the Triplex Laceration Index.

Experimentation was conducted using a commercially-available image processing toolbox, Image-Pro II™from Truevision, Inc. Image-Pro supports several standard image processing techniques such as contrast enhancement (including sliding and stretching), spatial filtering (including both convolution and non-convolution filters), histogram equalization, contouring, thresholding, and various mathematical image combination operators. Using Image-Pro, image processing can be judged for applicability to the laceration recognition task without requiring that each algorithm be developed and tested from scratch. The most promising algorithms can then coded to run at increased speed for inclusion into TRDC's program.

In preparation for experimentation with image processing techniques, a 6x7 cm rectangular sample was mounted for viewing. The sample was stretched between five pins located around the circumference of a 7 cm hole. Fig. 1 shows the sample mounted and stretched on the frame.

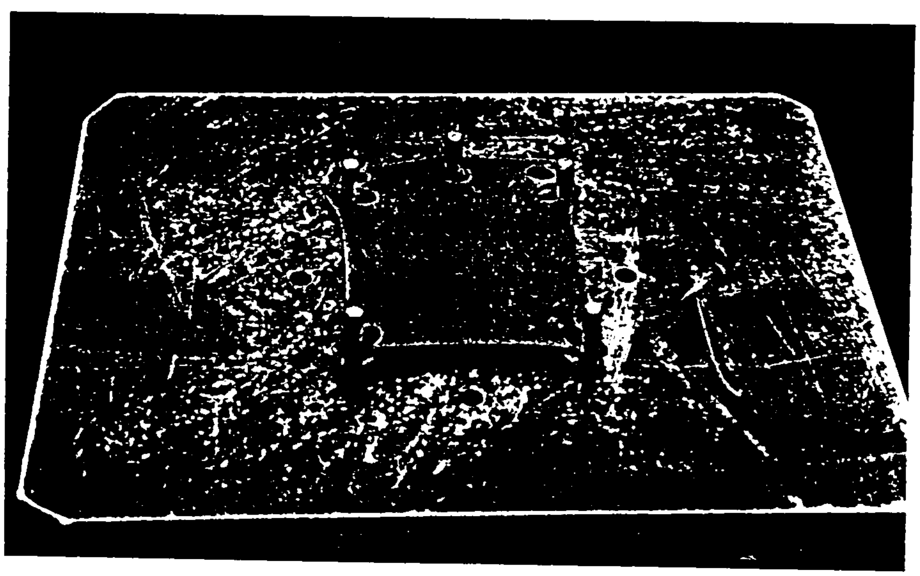

Figure 1. Sample Mounted in Frame

The sample contained lacerations resulting from impact tests conducted during the drop testing. At least two of the lacerations completely penetrated the sample. The sample was 2 mm thick, light blue in color, and of the material that, at this time, is most likely to be chosen as the face mask skin.

Experiments were conducted with several high pass filter and edge detection algorithms to identify and segment the lacerations from the background image. Each of the following algorithms, in isolation and in various combinations, was tested on the image: high pass filtering, edge detection (including Roberts, Sobel, and Laplace operators), median filtering, and several contrast equalization techniques. It was found that high pass filtering is of little use in isolating the laceration cuts from the background. Although the edges of the cuts are enhanced, high pass filtering also enhances the "salt and pepper" noise in the background, producing an image which appears grainy. Median filtering, which is often used prior to edge enhancement, does little to improve cut discrimination.

Of the various edge detectors, the Sobel operator appeared to be the most robust with respect to edge orientation. However, despite the utility of the Sobel in enhancing the edges of the bars and borders, application of the Sobel on the raw image resulted in the enhancement of all straight edges in the image. A means to discriminate between background and foreground was sought.

Thresholding was tried as a means to minimize the number of pixels to be processed following edge detection. It was found that pixel intensities of the lacerations were, in all cases, located in the 0-50 band, where pixel intensities are measured from 0 (dark) to 255 (white). Therefore, by simply thresholding the raw image at an intensity level of 50 following edge detection, a large portion of the unwanted pixels in the image are eliminated. Of course, an intensity histogram can be performed on the entire image in order to more carefully choose the threshold value, if necessary.

In summary, edge enhancement using the Sobel operator followed by thresholding has been selected as the means to discriminate between lacerations and background. The threshold value may have to be chosen dynamically from an intensity histogram analysis. Fig. 2 shows an image following edge enhancement and thresholding.

All tests described until this point were performed on a flat sample illuminated by diffuse overhead fluorescent lighting. Since the mounting plate had been placed on a desk top, the back of the sample was not illuminated, and lacerations that had completely penetrated the specimen could not be distinguished from those that had not.

A test was next performed with an illumination source behind the specimen. A low intensity 15 watt desk lamp was initially employed as the back light. The intensity of the lamp, however, was so great that the camera lens could not be stopped down enough to prevent saturation of the detector. White bond paper, as much as 50 mm thick, was then used to filter the back light. Fig. 3 shows the resulting image.

To date, an appropriate intensity of back light has not been found. When a light source of sufficient intensity to reveal the cut is employed, the contrast range of the camera detector is not large enough to detect the dark shadows in lacerations that do not penetrate the specimen. The basic problem appears to be that the contrast range of the solid state detector is not nearly as large as that of the human eye. Although an unaided can easily detect both penetrating and non-penetrating lacerations in the presence of back light, the camera cannot. Fig. 3 shows the candidate laceration objects resulting from processing of Fig. 2.

One solution to this problem is to take two pictures of the sample – one with back lighting; the other without backlighting. The two images could then be combined for further processing.

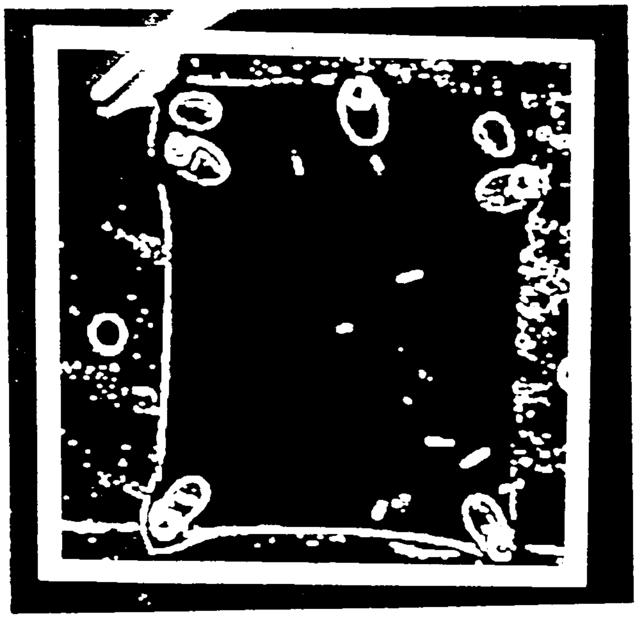

Figure 2. Image after Edge Enhancement and Thresholding

Figure 3. Processed Image of Smaple

One problem remaining with the camera system is that the measurement of lacerations on surfaces of the headform not perpendicular to the viewing axis of the camera is not accurate. This problem is being addressed by developing a three-dimensional (3D) model of the headform. The 3D model will be overlayed on the camera image. The location of any laceration detected in the camera image can then be associated with a region of the 3D model. Since the orientation of that region is known from the model, the actual length of the laceration can be readily calculated.

CONCLUSIONS

The research effort, culminating in the fabrication of the prototype face masks, proved the feasibility of manufacturing a face mask for Hybrid III dummies to measure facial laceration potential. Experiments indicated that the face mask can provide approximately the same Triplex Laceration Index score as the currently used double-layer chamois and that the mask should minimize a change in the dynamic impact response of the Hybrid III dummy [7]. The mask is expected to be significantly more consistent than oil-tanned chamois and should be manufacturable at a reasonable cost.

An accurate, repeatable face laceration mask system has commercial potential in the evaluation of materials used in automobile passenger compartments (such as windshield, dashboards, and steering columns) and in research aimed at developing an understanding of the many kinds of injuries that account for more than 40% of life lost in the US [7]. The most immediate uses for the face mask will be in the testing facilities of the Department of Transportation, windshield manufacturers, consumer protection foundations, auto makers, and insurance carriers, who conduct thousands of tests each year. Other agencies of DHHS, the Department of Defense, as well as manufacturers and consumer groups have begun to focus attention on the tremendous costs of injury, not only from traffic accidents, but home injuries, falls, and in battle. It is expected that the new face mask (or cover for other body areas) would open the door to more laceration injury studies.

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DISCUSSION

PAPER: **A System for Measurement of Laceration Potential**

SPEAKER: Don Myers

QUESTION: Kevin Drexler, P.E.

Lacerations don't appear to be as big a problem as they once were. In fact, very little seems to be occurring with regard to laceration, but one thing that is sort of a minor concern is that when you strike something on the surface and it is a blunt object, you can split the skin and not necessarily cut it. Will this technique attract that type of phenomena?

A: As I said, any kind of damage to the artificial skin will have an effect on the amount of light transmitted through that artificial skin can be detected with this technique, so if the skin is cut obviously that is going to create a through hole. If the skin is just thinned in some way, we'll be able to detect that. If the skin is abraded in some way, such that it becomes more dense, appears darker, yes we can also detect that. There are some other possible ways in which we might detect contusions and that might be to put microencapsulated particles, perhaps encoded with, containing different colors that break at different pressure levels and using a color camera or even a gray scale camera we might be able to extend this to contusions in that way too.