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Measurement of Abrasion Injuries in Crash-related Environments

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ABSTRACT

Abrasions are invariably present in crash events and are partly characterized by the quantity of skin tissue removed from the superficial skin layers through friction contacts. This paper reports work towards predicting tissue loss in crash events quantitatively in order to correlate simulations with real life clinical injury. Towards this, an experimental setup that mimics the crash environment in terms of loading and motion scenarios was developed. Recording of forces at the contact zone was accomplished by a two-channel load cell in conjunction with data acquisition system. A range of normal loads, sliding velocities and surface textures were used to abrade porcine skin specimens. The severity of abrasion to the skin following each abrasive test was estimated by the amount of tissue transferred to the abrading surface by protein mass measurement.

It was observed that the applied load and relative sliding speed have more pronounced effect on the abrasion rate than the dynamic coefficient of friction. The bio-tribological data obtained from the proposed friction and abrasion model can be used to correlate severity of abrasion in crash events from tribological properties such as skin abrasion rate and coefficient of friction.

1. Introduction

Road traffic crashes are emerging as one of the leading causes of fatalities and injuries worldwide [1]. Injuries from road crashes can be divided into two types: i) hard tissue injuries that affect bones such as bone fracture, bone contusion, etc. and ii) soft tissue injuries that involve damage of soft organs such as skin abrasion, ligament tear, aorta rupture, etc.

Epidemiological data indicates that the most common forms of soft tissue injuries include skin abrasions, contusions, avulsions and lacerations [2]. Abrasion is a mechanical injury characterized by wearing away of the superficial layer of skin by mechanical means, whereas avulsion is a more traumatic abrasion that removes all layers of the skin [3]. Though avulsion injuries are more severe, the mechanism of abrasion and avulsion injuries is similar. Among the trauma to the skin, abrasions are almost invariably present in crash events. Typical incidence of such injuries involves contacts of the skin with vehicle structural and safety components (such as the bumper, dashboard, seats, bonnet, seat belt, airbag and windscreen) or the road surface. These injuries may have the potential, to cause permanent scarring or pigmentation changes in the skin and to increase the risk of developing skin infection [4]. On the other hand, careful investigation of the abraded skin surface may allow determination the impact direction and nature of the causative vehicle component, which is useful information for accident reconstruction [5]. Despite their prevalence and clinical importance, abrasion and avulsion injuries following road crashes have not been studied extensively.

Research on skin abrasions in the past have been largely limited to airbag related abrasions. In addition, most of these studies have been conducted by deploying airbags onto the exposed skin of animals [6] and volunteers [4,7,8], making near normal contact. These types of abrasions are impact or pressure type of abrasions that are induced by normal loading from the impact of the airbag with the face and thoracic areas. Hurst et al. [9] tried to investigate the shear loading conditions encountered during airbag expansion and interaction with the upper extremities. They used a test rig whereby airbag fabric was accelerated across a skin specimen using a pneumatic high-speed impactor to produce abrasions on pigskin. In their study, however, the relationship between loading conditions and abrasion severity was not investigated.

Studies on frictional characteristics of the skin [10–13] and tribological evaluation of cosmetic products with respect to skin [14,15] have been reported. These experiments were however conducted on human volunteers and hence below the injury threshold. Other studies on friction induced injuries (injuries caused by friction force on the skin) mainly focused on blisters formation as a result of fabric friction on skin in military applications and sports [16–19]. FE simulation with a 3-D finite element model that simulates the foot–sock–insole contact was used by Dai et al. [20] to investigate the effect of sock fabrics on blister incidence.

Experimental data on sliding contacts of the skin with vehicle counter parts or the road surface as observed in crash environments are rare, despite these loading conditions being very common. In addition, experiments investigating the friction induced loading and associated

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attrition of skin due to abrasion, specifically, with the objective of injury prediction have not been reported so far. Hence, there is a need to characterize skin friction and abrasion resulting in damage and tissue loss under dynamic shear loading.

As mentioned previously, the term "abrasion" used in this paper refers to wearing or grinding away of superficial layer/s of the skin as it contacts a rough surface and moves along the surface. This leads to belief that the rubbing and the subsequent removal of skin tissue in sliding contacts resulting in abrasion injury to be an important manifestation of the friction and wear process. It is hence hypothesized that it is possible to predict abrasion severity in a given loading condition in terms of tissue loss by using a wear model.

Over the years, Finite element analysis (FEA) has emerged as a powerful tool for analyzing a very broad area of continuum problems [21]. FE method have been used to simulate tribological problems like sliding wear in metal to metal contacts [22,23] and polymers/elastomers to metal contacts [24,25] in variety of engineering and biomedical contexts. Studies investigating the tribological behaviour of a wide range of biological interfaces [26,27] and their artificial replacements [28–30] have been reported. The assessment of wear in most of these studies is accomplished by combining the finite element (FE) method with an established wear equation that estimates the wear at each node in the form of changes in nodal heights or positions of the mesh [31].

The present study is a part of ongoing research targeted to evolve a FE skin injury model that can be used to predict tissue abrasion by correlating mesh modification, due to relative nodal and elemental reconfigurations, to tissue loss and damage. Such a predictive model for skin friction and abrasion must incorporate bio-tribological properties like the coefficient of dynamic friction and the Skin Abrasion Rate (SAR). Measurement of these parameters through physical friction experiments coupled with bio-chemical analysis to estimate the resulting injury severity due to tissue loss following each abrasion test is reported here.

2. Experiments

2.1. Experimental Setup

A test setup, suitable to record contact force measurements while holding the skin in place and allowing the application of abrasive force directly on the exposed skin, was developed (see Fig. 1). A continuous loop of abrasive paper mounted on a belt-sander was made to slide past a sample of skin as a friction track for the test rig. A range of abrasion velocities for testing was achieved by using a variable frequency drive (VFD) controlled AC motor. Normal load was applied using dead weights via a parallelogram linkage arrangement. The linkage constrains the skin mount and the applied load to remain perpendicular to the abrading surface for small excursions. A counterweight was used to offset the weight of the load cell and linkage assembly. Contact forces developed during abrasion were continuously recorded by a two-channel load cell in conjunction with data acquisition system. High-speed digital video recording of each test at 100 fps was used for analyzing the belt velocity by image processing.

2.2. Materials and Methods

While the final interest is in human skin friction and abrasion properties, porcine skin was used in the present study because of the ease of availability of obtaining them as opposed to human skin for use in scientific research. Porcine skin is frequently used as a suitable model for human skin injury owing to its anatomical and physiological similarities with human skin [32,33] and its readily availability. In this study, porcine skin specimens (contact area 30 mm by 30 mm) were abraded over a range of normal loads (2.5 to 12.5 N), and sliding velocities (1–3.5 m/s). Details of experimental conditions used in the present study are shown in Table 1.

The skin specimens were harvested from the posterior forearm area of pigs aged approximately six months. The thickness of the specimen varied from 1.5 to 2.5 mm. Before the skin strips were cut from the subjects, square outlines were made on the skin with the inside dimensions of the clamping plate as described previously by Hurst et al. [9,34]. This allows to apply the in vivo tension that has been released during specimen excision and to restore to its original dimensions when the specimen is attached on the skin mount bracket as shown in Fig. 2.

Once the tissue is secured to the skin mount bracket by the clamping plate and four screws, the assembly is attached to the load cell, which was mounted earlier on the parallelogram linkage assembly. This allows recording of contact force while allowing the application of abrasive tangential forces directly on the exposed skin. After the skin specimen was fastened in place, the specimen holder was lowered until the skin contacts the abrading surface. Three type of abrasive papers 220-grit, 320-grit and 400-grit with effective grain size ranges 53–74 μm, 32.5–36.0 μm and 20.6–23.6 μm, respectively [35], have been used as sliding abrasive tracks. Lead weights were used to load the test specimen in the normal direction and the belt sander was set in motion by the VFD controlled AC motor. The parallelogram linkage arrangement ensures that the specimen holder and the applied load remain perpendicular to the abrading surface [36].

In this manner, each skin sample was abraded for approximately 1 min except in the tests investigating variation of protein mass as a function of sliding duration (Fig. 5(a)). The one-minute duration yields an adequate tissue material for protein analysis (minimum protein

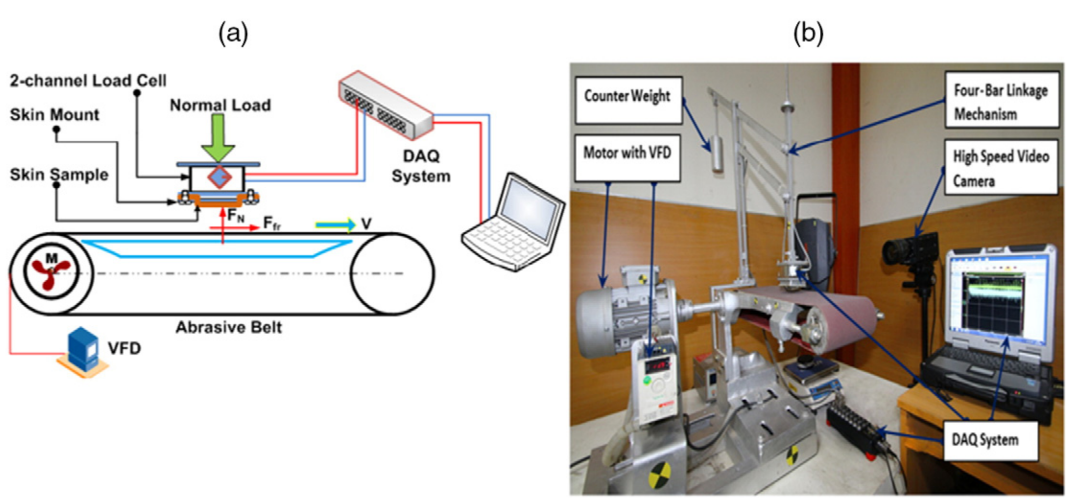

Fig. 1. (a) Schematic of abrasion tester showing the forces applied on the skin surface. (b) Photograph showing the entire test rig and its components.