DEVELOPMENT OF AN ANTHROPOMORPHIC THIGH FOR IMPACT ASSESSMENT

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INTRODUCTION

Modeling of body segments allows predictions to be made of their response characteristics during interactions with the environment. Once the segment or whole body has been replicated, their response to impact can be investigated. This, along with an injury tolerance level, provides an opportunity to assess the effectiveness of protective equipment. Head/neck models are used by the helmet industry to assess the effectiveness of crash and sport helmets. Whole-body models are used in the automotive and aircraft industries. No instrumented physical thigh model has been designed to assess soft tissue strain as a result of transverse impacts to the longitudinal axis. Predictions of soft tissue injuries such as thigh contusions cannot be made since there is no appropriate means to assess the protection from injury of the numerous thigh pads used in sport.

THIGH CONTUSION

A thigh contusion results from blunt physical trauma to the muscle. Bleeding and damage within the muscle causes pain, swelling, and a decreased range of knee motion. Contusions are often associated with athletic injury and most common in young males engaged in contact sport. Epidemiological data on thigh contusions have been gathered from various populations. It was found to be the most common injury in Australian footballers, accounting for 12.2% of all injuries (Seward and Patrick, 1992). The incidence rate (number occurring per 10,000 player hours) was 38 for Australian Rules and 102 for Rugby League (Seward and Orchard, 1992).

A study of American military cadets (Ryan et al., 1991) found the highest number of contusions occurred in tackle football but the injury rate (percentage injured per year) was greater in rugby (4.7%) and karate/judo (2.3%). Tackle football had an injury rate of 1.6%. It can be seen that thigh contusion is a common athletic injury.

The duration of disability due to a thigh contusion is variable and influenced by: severity, time elapsed before treatment is commenced, treatment protocol, and recovery criteria. It can be as short as two days for mild contusions and up to 35 days for severe contusions (Ryan et al., 1991). Seward and Patrick (1992) noted that 15.4 % of Australian footballers sustaining a thigh contusion missed a subsequent game. Although not usually as severe as skeletal or joint injuries, thigh contusions can result in significant periods of disability.

DETERMINATION OF INJURY TOLERANCE LEVELS

Several methods may be used to establish human tolerance levels: human volunteer tests, human cadaver research, animal research, and mathematical models. Human volunteers have traditionally been used to obtain non-injurious response characteristics. Under medical supervision, it may be possible to determine a tolerance level for mild contusions of human volunteers. These data can be compared to response data from cadavers and animals at the same levels of impact. Correlations or mathematical models may then be devised to extrapolate human volunteer results further into the injury domain.

Human cadaver data may be used to establish the internal force and the amount of dampening offered by the biological components (muscle, skin and fat). Intact anterior thigh tissue as well as the separate components may be placed on a force platform and drop tests performed. The data will be influenced by whether the cadaver is fresh or embalmed, age, and disease state. Some investigators have modified the cadaver data to include the effects of muscle tone (Lobdell et al., 1973). To account for the differences in response due to variations in sizes of the cadavers, the data should be scaled. It can then be applied to a representative anthropomorphic model such as the 50th percentile adult male.

Animal research provides the physiological responses not available in cadavers. For example, sheep have been used to investigate the reaction of the thigh to blunt trauma because their thigh muscles and vascular anatomy are claimed to be similar to those of human (Walton and Rothwell, 1983). The practise of anesthetizing the animal may have an effect upon the results. Due to species differences between human and test animals, the response must be scaled for size and geometry. The assumption is that the test animal, commonly primates, displays similar properties. Dimensional analysis has been used to scale primate response to head impact (Ono et al., 1980).

Mathematical models can be used to extrapolate animal and cadaveric data to living man. For instance, an impact-sensitivity technique using a linear spring-mass model was used to develope the Wayne State Tolerance Curve for head injury (Goldsmith, 1981).

METHODOLOGICAL CONSIDERATIONS

The experimental procedure deployed to determine the tolerance level should consider the environmental conditions in which the injury results. In sport, impact with an opponent's knee is the most common causative agent of thigh contusions (Jackson and Feagin, 1973; Ryan et al., 1991). The experimental striking mass should be of a configuration to simulate a knee (e.g. hemispherical). It could be argued that the mass of the striking implement can not approximate that of the leg or significant portion of body mass since this would severely limit the non-injurious margin (heights) for drop tests on human volunteers.

During athletic activities the thigh musculature is probably in a state of tension during impacts which cause contusions. Consideration should be given to drop tests on volunteers at various percentages of maximal voluntary isometric knee extension. An example of these data is presented in Table 1. The data were generated from a 26 year old male with a mid-thigh circumference of 58.5 cm and a mid-thigh skin fold of 17.2 mm. These data may be used to modify cadaver data for the effects of muscle tension. The parameter used to express the tolerance level will be an indirect measure. Contusions result from damage to muscular and vascular tissue. Ultimate strain of these tissues represent the injury mechanism actually involved. It is simpler to measure the input force which produces these strains. This can be accomplished by mounting an accelerometer to the striking mass.

Table 1. Anterior mid-thigh drop tests (mean of two trials).

% MVC	Drop height (cm)	Striker deceleration (peak g)	Rise time (ms)	Duration (ms)
0	5	6	29	65
0	10	10	24	50
25	10	11	19	42
50	10	14	15	33

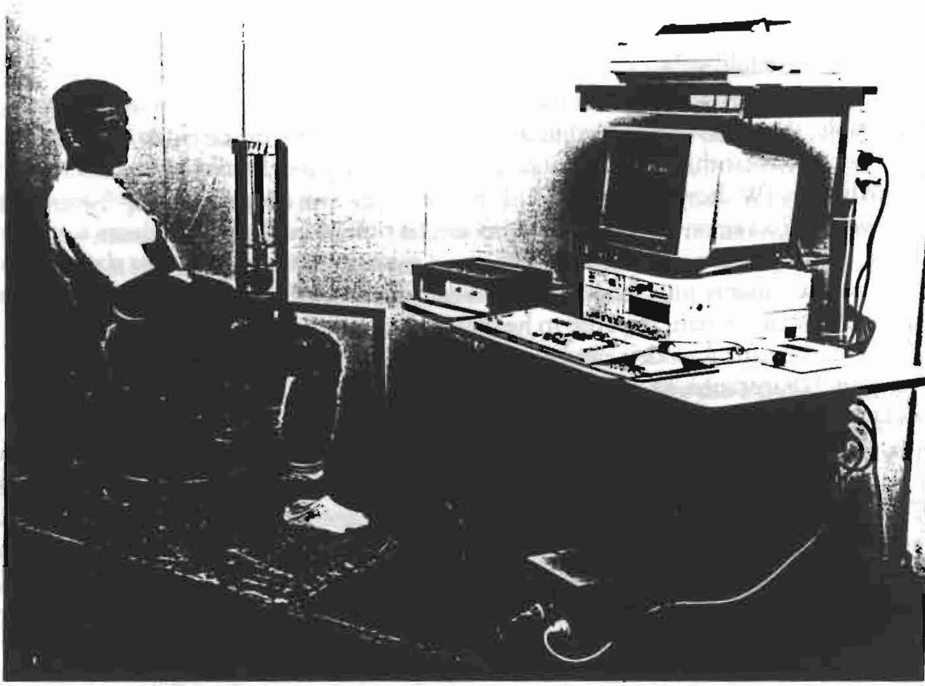

Figure 1. Experimental set-up.

Since biological materials are viscoelastic, the time history (strain rate) as well as the magnitude of the force need to be incorporated into the tolerance level. Difficulty arises when specifying a tolerance level due to a combination of factors: age, sex, anthropometry (thigh girth and skinfold), health status, muscle tension, and site of impact. It is clear that one absolute value can not with any certainty determine the likelihood of injury. The injury-predicting measure should attempt to account for these variables.

Once the response of the human thigh to transverse impacts has been established, synthetic materials displaying similar dampening properties (as determined from cadaver impact tests) may be selected to represent muscle and skin and fat. An anthropomorphic leg may be constructed with a force transducer or strain gauges positioned beneath the synthetic materials. It can then estimate the internal force and consequently predict contusions.

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