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Influence of anthropometry on the kinematics of the cervical spine and the risk of injury in sled tests in female volunteers

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Abstract

The objective of this study was to investigate the influence of anthropometric data on the kinematics of the cervical spine and the risk factors for sustaining a neck injury during rear-end collisions occurring in a sled test.

A rear-end collision with a velocity change (ΔV) of 6.3 km/h was simulated in a sled test with eight healthy female subjects. The study analysed the association of anthropometric data with the initial distance between the head and the head restraint, defined kinematic characteristics, the neck injury criterion (NIC) and the neck injury criterion minor (NICmin).

The head circumference is negatively associated ($r = -0.598$) with the initial distance between the head and the head restraint, the maximal head extension ($r = -0.687$) and the maximal dorsal angular head acceleration ($r = -0.633$). The body weight ($r = 0.800$), body height ($r = 0.949$) and thorax circumference ($r = 0.632$) are positively associated with the maximal ventral head translation. The neck length correlates positively with the NIC ($r = 0.826$) and negatively with the NICmin ($r = -0.797$).

Anthropometric factors influence the kinematics of the cervical spine and the risk of injury. A high risk of injury may be assumed for individuals with a small head circumference, long neck, tall body height and high body weight.

Keywords: Rear-end impact; Anthropometric; Head–neck kinematics; Volunteer sled tests; Whiplash

1. Introduction

Numerous passenger car crash tests (Penning, 1992; Castro et al., 1997) and sled tests (Ono and Kanno, 1996; Kaneoka et al., 1999; Mühlbauer et al., 1999; Watanabe et al., 2000; Blouin et al., 2003) carried out to investigate the in vivo crash situation have shown that the kinematics of the cervical spine are considerably more complex than originally assumed and they are dependent on various external influence factors. The influence of external "accident conditions" such as the impulse, acceleration and velocity change of the test sled (Boström et al., 2000; Brell et al., 2001; Siegmund et al., 2005) and the seat and head restraint properties (Jakobsson et al., 2000; Watanabe et al., 2000) on the kinematics of the cervical spine during rear-end collisions is thus largely known.

There is, however, limited information regarding the influence of occupant anthropometry and seated posture on the physical response of vehicle occupants. Epidemiological studies have found that women suffer whiplash more frequently than men (Farmer et al., 1999; Jakobsson et al., 2000) whereas the highest incidence of whiplash is between 20 and 24 years (Spitzer et al., 1995). So far most proposed explanations for gender differences in the injury risk are based on observations that females have a greater head mass for their neck area or neck strength than do males.

For the first time Siegmund et al. (1997) showed in a kinematics study that some kinematic parameters concerning the peak amplitude and time-to-peak-amplitude of the head acceleration and head motion varied significantly with gender. In a further study the previously observed relationship between some peak kinematic responses and gender appeared to be the result of

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Table 1
Subjects' anthropometric characteristics

Parameter	Definition	Median	Min	Max
Head measurement				
Head circumference (cm)	Head circumference 1 cm parallel cranial to the Frankfurter plane[a]	56	54	57
Neck measurements				
Neck length (cm)	Distance between the Protuberantia occipitalis externa and C7 in 0° position	14	12	16
Neck circumference (cm)	Average neck circumference on the level of the Protuberantia occipitalis externa and C7	32	29	36
Body measurements				
Thorax circumference (cm)	Thorax circumference on the level of the inferior margin of the sternum	90	81	101
Body height (m)		1.66	1.64	1.73
Body weight (kg)		63.5	53.0	73.0

[a] Frankfurter plane (auriculo-orbital plane): a plane passing through the inferior margin of the left orbit and the upper margin of each ear canal.

gender-based differences in height and therefore in the seated posture and to a lesser extend in occupant mass, head circumference, neck strength in extension and initial angle of the torso (Siegmund et al., 1999).

This suggests that the subject's gender or the associated anthropometric differences have an influence on the kinematics of the cervical spine and may thus also contribute to the individual risk of injury. In view of these findings it is therefore surprising that the influence of the anthropometry of the subjects on the cervical spine kinematics has not been further investigated (Siegmund et al., 1997; van den Kroonenberg et al., 1998; Siegmund et al., 1999). To study gender independently the influence of anthropometric factors on the kinematics of the cervical spine a homogeneous female population was investigated.

Against this background, the following questions were investigated:

1. Which anthropometric characteristics influence the initial distance between the head and the head restraint?
2. Which anthropometric characteristics influence the kinematics of the cervical spine?
3. Which anthropometric characteristics influence the injury criteria NIC and NICmin?

2. Methods

2.1. Subjects

Eight women aged 19–27 years (median: 23 years) without prior structural injuries to the spine participated in the study. The subjects were recruited by posting a notice at the university. Exclusion criteria were a history of whiplash injury of the cervical spine, neurological or psychiatric disease, functional impairments of the cervical spine or cervical spine pain. The approval of the Ethics Committee had been obtained for the performance of the experiments with volunteers.

The anthropometric characteristics that were determined were the head measurement (head circumference), the neck measurements (neck length and circumference) and the body measurements (thorax circumference, body height and weight) (Table 1). The anthropometric data were measured by a ruler and a tape measure with a precision of 0.5 cm. The body weight was asked for and documented in the unit kg. The median, minimum and maximum of the determined characteristics are represented in Table 1.

2.2. Experimental design

For the rear-end collision simulation we used a standard automobile seat (VW Passat, 1997 model, VW corporation, Wolfsburg, Germany) anchored to a sled platform (Fig. 1). An impactor platform was accelerated which, in turn, accelerated the seat sled to the appropriate velocity. The impact sled was abruptly stopped in order to prevent a secondary impact. Measurement of the sled acceleration was performed using a sensor (Endevco 2262, ±200 g, uniaxial x-direction, CFC 60, Endevco

Fig. 1. Front view of test sled.