Instrumented six degree-of-freedom paramedic mannequin neck design, informed by adult passive neck stiffness and range of motion data

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Introduction

Traumatic cervical spine injuries of ten have devastating consequences and outcomes may be exacerbated by suboptimal neck immobilisation. Immobilisation practice may be improved by training with patient simulator mannequins (PSMs). However, there are limited data describing the response of the neck to loads applied absent of muscle activation, and this restricts the design of improved PSM necks. The aims of this study were to: (1) measure passive neck stiffness and range of motion (ROM); (2) examine their dependence on age and sex; and, (3) develop a PSM neck with that data.

Methodology

Two custom low-friction testing apparatus were designed to perform flexion, extension, lateral bending and axial rotation tests. 40 males and 40 females (age: 20–80 years) lay on a clinical bed while their head was slowly rotated in each apparatus, by the researcher, to the maximum ROM (Figure 1). Head-torso motion, and loads applied to the head, were measured and real time neck muscle activation feedback was provided. Stiffness was calculated in three defined zones of each moment-angle relationship. The effect of age, sex, and their interaction, on ROM and stiffness were examined with linear regression and linear mixed models. Post-hoc tests were performed if the age-sex interaction was significant (SPSS, IBM, USA; p<0.05). For brevity, lateral bending and axial rotation data are reported as left/right means.

A six degree-of freedom neck was developed to interface with the head and torso of an existing PSM (Figure 2). It comprised a central silicon column and six string-potentiometers in a Stewart-platform configuration to provide real-time head-neck motion data. Motion limiters and spring-string systems were implemented to provide capacity to adjust ROM and stiffness, respectively. The PSM neck underwent similar test protocols as described above.

Results

ROMs were not dependent on age (0.05<p<0.49) or sex (0.21<p<0.97) [flexion 46±11, extension 63±14, lateral bending 37±11, axial rotation 66±17 degrees]. Age effects on extension (zone 3) and lateral bending (zone 1-2) stiffness were sex dependent (p<0.01), with 3.16, 4.56 and 9.08 Nmm/deg/yr increase for males and 1.10, 2.13 and 3.94 Nmm/deg/yr increase for females (Figure 3). Stiffness increased with age, independent of sex, in extension (zone 2: 1.32 Nmm/deg/yr, p<0.01), lateral bending (zone 1: 0.37 Nmm/deg/yr, p<0.01) and axial rotation (zone 1-3: 0.19, 0.58, 1.11 Nmm/deg/yr; zone 1: p=0.045, others p<0.01). The PSM neck had similar ROM as participants in flexion and axial rotation. PSM neck stiffness was within young adult’s range in extension, axial rotation (zone 1-2), and flexion and lateral bending (zone 1), but had generally lower stiffness than 60+yr adults.

Conclusions

Adult passive neck ROM was not dependent on age or sex. Neck stiffness generally increased with age in extension, lateral bending, and axial rotation. The current PSM neck design has human-like ROM and stiffness in some motions and some zones. With increased stiffness and modified extension and lateral bending ROM, this instrumented PSM neck could enhance neck immobilization training.