Angular rate effect on stiffness and damping characteristics of different head/neck assemblies during cyclic tests

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Introduction: Head and neck injuries are a serious threat in everyday and sport activities. Thus, a proper testing of protective gear is crucial to guarantee their effectiveness and to support companies towards their development. To achieve this goal, surrogates adopted in testing must be improved: researchers are developing their own prototypes as alternatives to the Hybrid III neck [1]. To further improve the bio fidelity of neck surrogates, a set of new prototypes aiming to obtain a neck stiffness closer to cadaver literature data [2] is under development. The novel method here presented was developed to characterize the cyclic/impact response of head/neck assemblies. This approach is useful since available stiffness data are typically obtained with static or quasistatic data [1] but the response of these surrogates may not be linear with flexion/extension angular rate.

Methods: Two neck surrogates, a 50th male percentile Hybrid III (JASTI, Japan) and a novel biofidelic neck surrogate named BNP1 were assembled to a 50th male percentile Hybrid III head form (JASTI, Japan). The head/neck assembly was mounted over a K6D68 six-axis load cell (ME-Systeme, Germany) which was secured to a horizontal sliding platform. The platform was actuated using a 200 mm stroke MTS 242 servo hydraulic cylinder (MTS, USA) and sine waves of different amplitudes to increase the flexion/extension angular rate (Figure 1a). Loads at the neck base were acquired with the six-axis load cell synchronously to the displacement imposed by the cylinder. Motion of the head/neck assembly was acquired using a Bonita 3D Motion Capture System (Vicon, USA). Static stiffness of the two neck surrogates was also measured using an experimental setup like the one adopted by Nightingale [2]. Kinematics of the neck were reconstructed from marker data of two reference systems: lower neck base and head. From the bending moment vs flexion/extension angle cross plot as in Figure 1.b, two parameters were calculated: the sagittal neck stiffness (K_S) as the slope of the linear regression of data, and the dissipated energy (E^*_d) as the area of the hysteresis cycle normalised to the flexion/extension range in radians.

Results: Hysteresis cycles of the two necks at different angular speeds are reported in Figure 1b. The stiffnesses and the normalized energy values are reported in Table 1.

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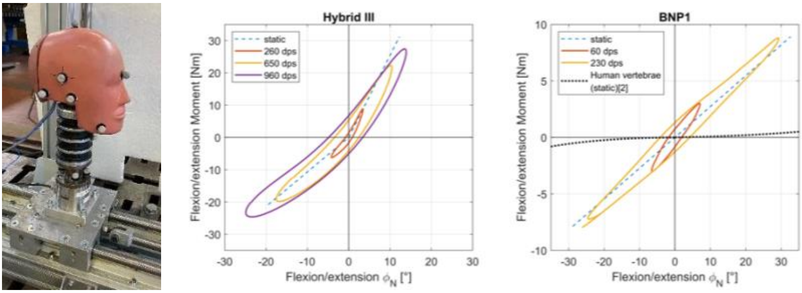

(a) (b)

Fig. 1: (a) Hybrid III head/neck assembly prepared with markers mounted on the load cell over the sliding platform; (b) hysteresis plots obtained from Hybrid III and BNP1 data.

Table 1: Sagittal neck stiffnesses and normalized dissipated energy calculated for each test.

	Ang. Rate [dps]	$K_{S\ flex}$ [Nm/rad]	$K_{S\ ext}$ [Nm/rad]	Flex/Ext ratio	E^*_d [J/rad]
Hybrid III	*0*	*145.5*	*61.3*	*2.4*	-
	260	160.7	72.9	2.2	2.45
	650	142.9	52.4	2.7	7.52
	960	128.4	47.9	2.7	9.63
BNP1	*0*	*15.6*	*15.6*	*1.00*	-
	60	26.3	24.4	1.07	1.21
	230	17.4	17.2	1.01	1.64
Nightingale	*0*	*1.9*	*2.44*	*0.8*	-

Discussion: The Hybrid III presents a higher stiffness in flexion than in extension as expected [1], due to the cuts on the frontal portion of rubber disks; BNP1 shows an unbiased behaviour in the sagittal plane. At increasing angular rate, stiffness decreases and normalized energy increases; static stiffness differs from the cyclic values, possibly due to the different setups. Hybrid III, BNP1 and cadaver stiffness data differ from each other of about an order of magnitude, showing a trend towards better bio fidelity of BNP1. Square/ramp movements of the platform are also possible to simulate a step flexion/extension movement as well as side bending. This method could be adapted to study the effect of neck protectors on head/neck overloads.

1. Walsh E., Kendall M., Post A., Meehan A., Hoshizaki T. B. (2018). Comparative analysis of Hybrid III neckform and an unbiased neckform. Sports Engineering volume 21, pages 479–485.
2. Nightingale R.W., Winkelstein B.A., Knaub K. E., Richardson W.J.L., Jason F., Myers B.S. (2002). Comparative strengths and structural properties of the upper and lower cervical spine in flexion and extension. Journal of Biomechanics 35, 725–732.

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