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Experimental analyses of the retinal and subretinal haemorrhages accompanied by shaken baby syndrome/abusive head trauma using a dummy doll

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ABSTRACT

Introduction: We explored several modes of violent shaking using a dummy doll with an eyeball model to reproduce abusive events that lead to retinal haemorrhages (RH) seen in shaken baby syndrome or abusive head trauma (SBS/AHT).
Materials and methods: A dummy doll equipped with an eyeball model was prepared. The eyeball model was filled with a model of vitreous body, *i.e.* agar gel or water, and was with a pressure sensor to measure normal stress.
Results: The modes of shaking were classified into three patterns, *i.e.* fast shaking with the fore arms, fast shaking with the whole arms and synchronized shaking with the whole arms. The frequency of the cyclic acceleration–deceleration history experienced by the head of the dummy doll was 5.0, 4.0 and 2.2 Hz, respectively, with the maximum acceleration of 20, 20 and 60 m/s^2, respectively. We considered the last of these three modes of shaking as possibly corresponding to the worst case of violent shaking. This mode of shaking could be instructed to volunteers who acted as imitate perpetrators, and resulted in both increased peak intensities of the acceleration experienced by the head of the dummy doll and increased stresses on the retina at the posterior pole of the eyeball model.
Discussion: The time integral of the stress through a single cycle of shaking was 107 Pa·s, much larger than that of a single event of fall, which resulted in 60–73 Pa·s. Taking into account that abusive shaking is likely to include multiple cycles, the time integral of the stress due to abusive shaking can be even larger. This clear difference may explain why RH in SBS/AHT is frequent, while RH in accidental falls is rare.

Introduction

Shaken baby syndrome or abusive head trauma (SBS/AHT) is a series of abusive head injuries caused by abusive shaking. Some of the characteristic findings in SBS/AHT are subdural haemorrhages, cerebral contusion and extensive retinal haemorrhages (RH) [1,2]. The diagnosis of SBS/AHT can be difficult because external bruising, which can be a stark evidence, has been reported to be absent in a significant minority (21%) of fatal abusive head injuries [3]. Although the mechanism of RH on abusive shaking is not clearly understood, paediatric ophthalmologists examine the fundus of children suspected to having been abused because RH is found in 83% of the shaken children [4]. RHs caused by SBS/AHT are often bilateral, involve the preretinal layer, cover the macula and extend to the periphery of the retina; while those due to accidental impacts are usually unilateral, accompanied by scalp haematoma, restricted to cases that cause severe epidural haematoma [5,6]. While differential diagnosis of SBS/AHT is carefully made with the aid of these characteristic tendencies, that accidental falls also could cause RH might still be used as an excuse by a perpetrator. Therefore, elucidation of the mechanism of RH in SBS/AHT can be very helpful for rational identification of child abuse.

The diameter of an eyeball is *ca.* 24 mm in adults and *ca.* 16 mm in newborns. The outermost layer of an eyeball consists of the cornea and the sclera, which maintain the spherical shape of the eyeball. The cornea is a transparent membrane located in the anterior surface to lead light into the eyeball, whose area occupies 1/5 of the surface of the eyeball. The sclera is a white opaque and strong membrane that occupies the rest 4/5 of the surface of the eyeball.

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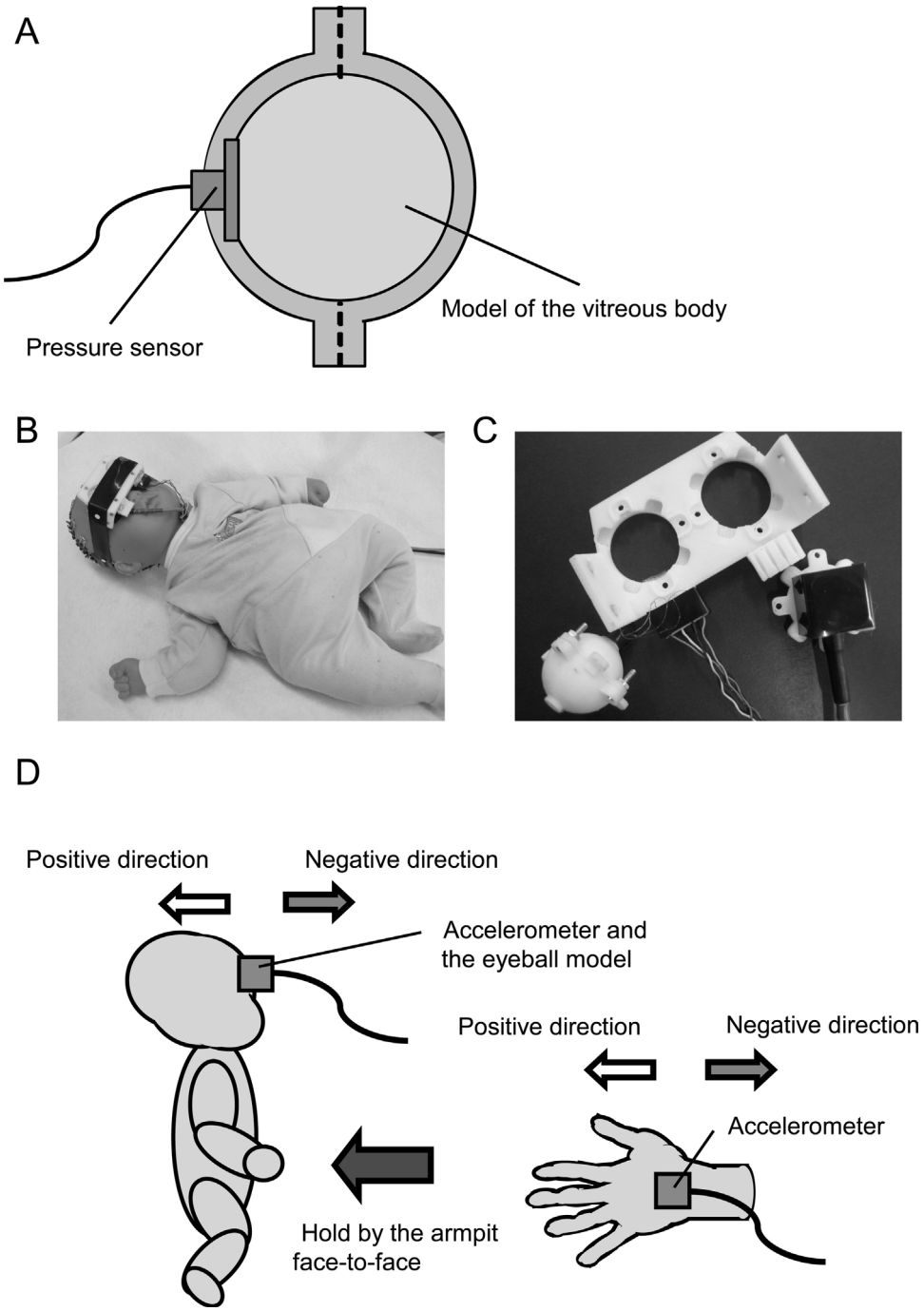

Fig. 1. Experimental setup to simulate abusive shaking. The plastic casing of the eyeball model contained either agar gel or water as a model of the vitreous body (A). A pressure sensor was placed on the inside wall of the casing. A dummy doll simulating an one-month-old infant was prepared (B). The eyeball model (bottom left) and an accelerometer (bottom right) were fixed via an attachment (top) to the head of the doll (C). The coordinate system of the accelerometers in the simulation of violent shaking is shown (D). An imitate perpetrator held the dummy doll by the armpits face-to-face. An accelerometer was attached to either of the hands of the imitate perpetrator, the positive direction of the coordinate system of which corresponded to the direction of the stroke moving away from the body of the imitate perpetrator. Another accelerometer was attached to the head of the dummy doll parallel to the sagittal axis, the positive direction of the coordinate system of which corresponded to the posterior direction of the head of the dummy doll.

The retina, the tissue that senses light, is a thin and soft membrane located inside the eyeball. The vitreous body is a transparent tissue that occupies about 2/3 of the volume of the eyeball. The ingredient of gel of the vitreous body decreases along ageing [7].

Duhaime et al. [8] estimated the acceleration experienced by the head of an infant during abusive shaking, using a dummy doll equipped with an accelerometer. Their simulated abusive shaking had a frequency of *ca.* 4 Hz, according to commonly described situation of SBS/AHT. Nevertheless, the actual situation of abusive shaking may not be correctly described because of the scarceness of objective witness.

The hypothesis of vitreoretinal traction, which postulates that the stress applied on the retina drawn by the vitreous body during abusive shaking causes RH, is attracting attention as the major factor of RH in SBS/AHT [9]. Hans et al. [10] and Rangarajan et al. [11] tried to verify this hypothesis by estimating the stress applied on the retina, using finite element method. However, both of these studies assumed some frequency and amplitude for the abusive shaking.