Auris Nasus Larynx 39 (2012) 540–543

Contents lists available at SciVerse ScienceDirect

Auris Nasus Larynx

journal homepage: www.elsevier.com/locate/anl

# Time course of the recovery of three-dimensional eye position in patients with acute cerebellitis

Takeshi Tsutsumi [a,*], Takuo Ikeda [b], Yutaka Fukuoka [c], Kensuke Watanabe [d], Shigeru Kikuchi [a]

[a] Department of Oto-Rhino-Laryngology, Saitama Medical University, Saitama Medical Center, Kamoda 1981, Kawagoe-shi, Saitama 350-8550, Japan
[b] Department of Oto-Rhino-Laryngology, Tsuzumigaura Handicapped Children's Hospital, Japan
[c] Laboratory of Biosystem Modeling, Institute of Biomaterials and Bioengineering, Japan
[d] Yoyoginomori ENT Clinic, Japan

ARTICLE INFO

*Article history:*
Received 14 June 2011
Accepted 22 October 2011
Available online 12 November 2011

*Keywords:*
Acute cerebellitis
Listing's plane
Vestibule
Gravity
Internal model

ABSTRACT

Listing's plane is a construction derived from eye position and reflects gravitational orientation. The cerebellum plays a key role in orienting and integrating sensory input concerning gravity from visual, vestibular and proprioceptive apparatuses. This suggests that the thickness of Listing's plane could serve as a novel parameter for evaluating the accuracy of the constructed gravity-oriented internal model. We report a case with acute cerebellitis along with data on Listing's plane, calculated from consecutive infrared video-oculogram recordings. We found thickening of Listing's plane at the early stage of the disease, and a gradual reduction of the thickness into normal range in parallel with the recovery of the patient's posture and gate. Notably, clinical improvement of the patient's posture was delayed relative to the normalization of the thickness of Listing's plane. The thickness of Listing's plane reflects the stability of the cerebellar-mediated cognitive gravitational reference frame. This thickness value could serve as a parameter to quantitatively evaluate the function of the constructed internal model. Recovery from cerebellar ataxia (manifested as normalization of the thickness of Listing's plane) was followed by recovery of muscular strength lost during the period the patient was by his disease forced to assume a lying position.


## 1. Introduction

Systemic viral or bacterial infections can cause acute cerebellitis, which manifests as truncal ataxia, headache, nystagmus, tremor and myoclonic jerks, limb and/or gait ataxia, dysarthria, and abnormal eye movements [1]. Most frequently involved agents are herpes simplex virus, varicella-zoster virus, cytomegalovirus, Epstein-Barr virus, rubeola, rubella, Bordetella pertussis, diphtheria and coxsackie virus [2]. The origin of the postural and gait disturbance may be ataxia of the lower limb and trunk, accompanied by instability of the internal model caused by cerebellar mis-integration of sensory (visual, vestibular and somatosensory) inputs. The phenomenon generally resolves after a few months of convalescence.

In healthy subjects, eye position during steady fixation and smooth pursuit adheres to Listing's law [3–6], which specifies the so-called Listing's plane, on which all rotation axes are held when expressing ocular position as a single rotation from a common reference position. The cerebellum is thought to be involved in maintaining eye position on Listing's plane, and cerebellar deficit reportedly leads to violation of Listing's law [7,8]. Such violations would disturb the integration of the sensory input used to construct the gravity-oriented internal model, which might destabilize Listing's plane, thereby thickening it.

In the present report, we describe a case of acute cerebellitis in which the patient exhibited a thickening (torsional drift) of Listing's plane. The thickness of the plane declined gradually as the postural disturbance diminished. The utility of this thickness as a parameter for evaluating the stability of the internal model is discussed [9].

## 2. Methods

During their examination, subjects wearing infrared CCD-mounted goggles sat on a chair with their head upright and fixed on a headrest. The CCD camera in the goggles was mounted in front of the subject's left eye, leaving the right eye's field of view unobstructed. Fifty cm in front of the subject's right eye, we placed a screen on which there were 9 fixation points respectively positioned at the center, at the four vertices of a square with sides of 15 cm, and at the centers of each of the 4 sides of the square. This square fit entirely within the subject's right visual field through the goggles. The subjects were instructed to fixate for 1 s on each of the 9 fixation points consecutively, and the eye position was recorded as a video 9 s in duration.

* Corresponding author. Tel.: +81 49 228 3400; fax: +81 49 225 6312.
*E-mail address:* takeoto@saitama-med.ac.jp (T. Tsutsumi).

0385-8146/$ – see front matter 
doi:10.1016/j.anl.2011.10.006

The recorded video images were initially analyzed using a macro program for ImageJ (NIH, USA), which was obtained via the Internet from the Department of Otolaryngology, Yamaguchi University, Japan (http://ds.cc.yamaguchi-u.ac.jp/~ent/gankyu3d/ikeda.html) [10,11]. The program translated the video images of the subject's eye to horizontal and vertical coordinates by detecting and pursuing the center of the pupil. In addition, the rotational angular position around the pupil was calculated using the pattern on the iris as a reference. Actually, the entire iris pattern in the reference position was overlaid on the same area of the iris pattern in the aimed position; it was then rotated in 0.1° steps, and the angle at which both iris patterns showed the greatest match was determined. These data were then transformed onto a rotational vector coordinate system via Fick's coordinate frame.

### 2.1. Translation to Fick's coordinate frame

We translated the horizontal ($H$), vertical ($V$) and torsional ($T$) positions obtained from ImageJ to $z, y, x$ values on Fick's coordinate frame using a convention in which $H$, $V$ and $T$ were positive when the eye turned rightward, upward and clockwise, respectively, from the subject's perspective. The $X$-, $Y$- and $Z$-axis of the Fick's coordinate frame represent forward, leftward and upward, respectively, so that positive values of $x$, $y$ and $z$ indicate clockwise rotation of the eyeball along each axis. The $X$-axis was adjusted toward the gaze direction at the reference position.

On the Fick's coordinate frame, $|y| = |V|$ (Fig. 1a).

In Fick's coordinate system, rotation around the axis was achieved in the order $Z$, $Y$ and $X$. In this process, following axes were also rotated, which yielded an inconsistency between $H$ and $z$. Fig. 1b indicates that $z = -\arcsin(\sin H/\cos V)$.

The locus of the center of the pupil at the second rotation (around the $Y$-axis) was formulated as follows:

$$\begin{array}{l} X^2+Y^2+Z^2=1 \\ Y=(\tan z)\times X \end{array} \quad (Z\neq 0 \text{ viz. } H\neq 0)$$

A projective figure of this locus on the $Y$–$Z$ plane (Fig. 1c) was calculated by eliminating $X$, as follows:

$$Y^2\left(1+\frac{1}{\tan^2 z}\right)+Z^2=1$$

The formula was then differentiated as follows:

$$2\left(1+\frac{1}{\tan^2 z}\right)Y+2Z\frac{dZ}{dY}=0 \qquad \frac{dZ}{dY}=-\left(1+\frac{1}{\tan^2 z}\right)\frac{Y}{Z}$$

By then substituting $Y = -\sin H$, $Z = \sin V$, we obtained the formula

$$\frac{dZ}{dY}=\left(1+\frac{1}{\tan^2 z}\right)\frac{\sin H}{\sin V}=\frac{1}{\sin^2 z}\frac{\sin H}{\sin V}$$

Finally, we obtain the formula as follows:

- When $H\times V>0$, ($H>0$, $V>0$: rightward and upward eye position or $H<0$, $V<0$: leftward and downward eye position)
  $$\frac{dZ}{dY}>0, \qquad x=T+\left(\frac{\pi}{2}-\arctan\frac{dZ}{dY}\right)$$
- When $H\times V<0$, ($H>0$, $V<0$: rightward and downward eye position or $H<0$, $V>0$: leftward and upward eye position)
  $$\frac{dZ}{dY}<0, \qquad x=T-\left(\frac{\pi}{2}+\arctan\frac{dZ}{dY}\right)$$
- When $H\times V = 0$, ($H = 0$ or $V = 0$)
  $$x=T$$

Here we obtained the expression on the Fick's coordinate frame.

### 2.2. Translation to the rotational vector coordinate frame

Each rotation of Fick's coordinate frame provided the rotational quaternions. By composing these quaternions, we could precisely determine the pseudovector that represents the rotational axis and angle [12,13]. To build a rotational quaternion, we defined rightward rotation around an axis as positive. As a head-fixed reference frame axis, $x$ represents forward with respect to the subjects (i.e., roll plane rotation), $y$ represents leftward (i.e., pitch plane rotation) and $z$ represents upward (i.e., yaw plane rotation). When plotting this pseudovector, we defined its length to be the rotational angle (deg). All images in one recorded sequence were translated to pseudovectors, each of which represented a rotation from the reference position to each eye position, and were plotted together on one diagram. The resultant diagram gave the reference position-based positional plane, which provided the direction of the subject's primary position. These enabled us to obtain the primary position-based, so-called, Listing's plane, on which the reference position coincides with the primary position. The thickness of this plane can provide the magnitude of its torsional drift, which is represented as the standard deviation (SD) of the torsional value.

To obtain normal control data, 14 healthy subjects (11 males and 3 females, mean age: 36.8 years) with no history of ear disease or vertigo participated in the experiment. The average thickness of Listing's plane (represented by the SD of the torsional value for each subject) was $0.769 \pm 0.369°$. All protocols and examination procedures were approved by the Ethical Standards Committee of Dokkyo Medical University, Koshigaya Hospital and were in accordance with the Declaration of Helsinki. Each subject's consent was obtained after explaining the details of the study.

## 3. Case report

A 56-year-old male was admitted to the hospital complaining of continuous dizziness and severe postural disturbance that had persisted for 5 days. His past medical history was unremarkable. Neurological examination revealed ataxia of the trunk (difficulty in independently maintaining a standing or sitting posture), upper limbs and fingers (dysgraphia and difficulty with typing email), but no cranial nerve paralysis, dysdiadochokinesia or neck stiffness. A complete blood count showed a leukocyte count of 5300 $mm^{-3}$ with 46% polymorphonuclear leukocytes and 40% lymphomonocytes, accompanied by a high rate of atypical lymphocytes (13%). C-reactive protein was slightly elevated (0.66 mg/dL). His biochemical study showed elevated AST (180 U/L), ALT (253 U/L), ALP (566 U/L), LDH (692 U/L), gamma-GTP (274 U/L) and direct-bilirubin (0.35 mg/dL). A serological test for Epstein-Barr virus antibody showed increased VCAIgM (10) and VCAIgG (160). Examination of the CSF showed a high protein level (89.3 mg/dL) accompanied by a normal glucose level (54.0 mg/dL); the cell count was 12 $mm^{-3}$ and was 100% lymphomonocytes. Neuro-otological examination revealed slight downbeat nystagmus under non-fixating conditions, which disappeared within 1 week. Fixating nystagmus was not observed. Computed tomography (CT) and magnetic resonance imaging of the patient's brain were normal. CT of his chest and abdomen done to rule out paraneoplastic syndrome were unremarkable.

Hydrocortisone therapy at a dose of 300 mg/day was started on day 1, after which the dose was reduced gradually until the drug was stopped on day 21. On admission, the patient could neither stand nor sit by himself. After the 3 weeks of therapy, he could stand by himself with his eyes open, and after 4 weeks he could walk alone with a stick and was discharged. After 2 months, he was able to walk without a stick. His truncal and upper limb ataxia also