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Body sway increases immediately after strabismus surgery.

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Abstract

The purposes of this study were to examine whether body sway is altered immediately after strabismus surgery in children and to find preoperative clinical factors associated with body sway. In a prospective study, body sway was measured on 1-3 days before surgery and on the third day after surgery; for the measurements, computerized static stabilometry was carried out on 28 consecutive patients with strabismus (age range: 3 to 12 years old; mean: 7.4) who underwent strabismus surgery under general anesthesia. The linear length of the sway path (cm), the linear length of the sway path in a particular unit of time (cm/second), and the area of the sway path (cm2), indicative of the extent of body sway, all increased significantly among a total of 28 patients in both conditions of the patient's eyes open and closed, as well as among those in a subgroup of 16 patients with exotropia, after they had undergone strabismus surgery ($p < 0.05$, Wilcoxon signed ranks test). The center of pressure along the Y axis of orientation from the toe to the heel was found to deviate significantly toward the heel postoperatively, as compared with the preoperative center in the subgroup of 16 patients with exotropia ($p < 0.05$). Before surgery, 15 patients with no stereoacuity exhibited a greater amount of body sway when their eyes were open than did 13 patients with measurable stereoacuity ($p < 0.05$, Mann-Whitney U-test). In the subgroup of 16 patients with exotropia when their eyes open, 3 patients with abnormal head posture exhibited more extensive body sway than did 13 patients without abnormal head posture ($p < 0.05$). Body sway was found to significantly increase immediately after strabismus surgery in children with strabismus. Stereoacuity and abnormal head posture are 2 clinical factors associated with preoperative postural instability.

KEYWORDS: body sway, strabismus surgery, exotropia, estropia, stabilometry

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Original Article

Body Sway Increases Immediately after Strabismus Surgery

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The purposes of this study were to examine whether body sway is altered immediately after strabismus surgery in children and to find preoperative clinical factors associated with body sway. In a prospective study, body sway was measured on 1-3 days before surgery and on the third day after surgery; for the measurements, computerized static stabilometry was carried out on 28 consecutive patients with strabismus (age range: 3 to 12 years old; mean: 7.4) who underwent strabismus surgery under general anesthesia. The linear length of the sway path (cm), the linear length of the sway path in a particular unit of time (cm/second), and the area of the sway path (cm^2), indicative of the extent of body sway, all increased significantly among a total of 28 patients in both conditions of the patient's eyes open and closed, as well as among those in a subgroup of 16 patients with exotropia, after they had undergone strabismus surgery ($p < 0.05$, Wilcoxon signed ranks test). The center of pressure along the Y axis of orientation from the toe to the heel was found to deviate significantly toward the heel postoperatively, as compared with the preoperative center in the subgroup of 16 patients with exotropia ($p < 0.05$). Before surgery, 15 patients with no stereoacuity exhibited a greater amount of body sway when their eyes were open than did 13 patients with measurable stereoacuity ($p < 0.05$, Mann-Whitney U-test). In the subgroup of 16 patients with exotropia when their eyes open, 3 patients with abnormal head posture exhibited more extensive body sway than did 13 patients without abnormal head posture ($p < 0.05$). Body sway was found to significantly increase immediately after strabismus surgery in children with strabismus. Stereoacuity and abnormal head posture are 2 clinical factors associated with preoperative postural instability.

Key words: body sway, strabismus surgery, exotropia, esotropia, stabilometry

Equilibrium function, including postural control, is assessed clinically in the context of routine otolaryngological and neurological examinations. Body sway is a clinical manifestation of the equilibrium function and is used as a clinical test to assess cerebellar and vestibular function [1, 2] as well as to assess the muscle balance of the lower extremities or the lower back [3-5]. This test has been also used to study the effects of alcohol intake [6] and to evaluate potentially disease-related symptoms such as

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dizziness [7] and headache [8]. Computerized static stabilometry is recognized as a reliable and non-invasive approach to the quantitative evaluation of body sway [9-12].

To date, equilibrium function testing has not been routinely performed in patients with strabismus. In previous studies carried out in Sweden, body sway was measured by a roughly accurate technique in children with either esotropia or exotropia, and it was revealed that body sway is greater in children with esotropia [13-15]. However, those studies provided no detailed analysis of body sway among patients with strabismus. Furthermore, the effects of strabismus surgery on body sway have not yet been reported in the literature. Therefore, in the present study, we measured body sway in patients before and after strabismus surgery using computerized static stabilometry in order to determine whether or not strabismus surgery would influence postural control. In addition, we investigated the potential relationship of body sway to clinical factors such as binocular function and abnormal head posture observed before surgery.

Patients and Methods

Patients. In a prospective study, stabilometric measurements were carried out both preoperatively and postoperatively in 28 consecutive patients who underwent strabismus surgery at Okayama University Hospital from July 2001 to February 2002. The patients were 14 boys and 14 girls, with an age range at the time of surgery from 3 to 12 (mean: 7.4) years old (Table 1). The present strabismus surgery was the second surgical intervention in 3 of these patients. A subgroup of 16 patients with exotropia, including 14 with intermittent exotropia and 2 with exotropia, consisted of 8 boys and 8 girls (age range at the time of surgery: 3-12 years old; mean: 7.9) (Table 1). No patients had neurological deficits, developmental delay, or any other known diseases.

Examination schedule. The patients were hospitalized as part of a standard treatment course, and in accord with a clinical pathway applied in the context of the Japanese Health Care System, *i.e.*, admission on Tuesday, surgery under general anesthesia on Friday, removal of eye shields on Saturday, and discharge on Monday. Preoperative stabilometric measurements were carried out on Tuesday, Wednesday, or Thursday, *i.e.*, 1-3 days before the surgery whereas the postoperative measurements were carried out consistently on Monday, *i.e.*, 3 days after the surgery. The following ophthalmological and strabismological examinations were performed prior to surgery: visual acuity testing, slit-lamp biomicroscopic and funduscopic examinations, alternate prism and cover tests carried out both at 0.3 m as well as at 5 m, the Bagolini striated glasses test, and the TNO stereoscopic test (Table 1). Patients who were unable to understand the instructions for the stabilometric measurements were excluded from the study. All of the procedures used in the present study conformed to the Declaration of Helsinki.

Stabilometric measurements. The center of pressure between both feet was measured by stabilometry with a computerized vertical force platform (Gravicorder GS-11; Anima Co., Tokyo, Japan) while the patients were instructed to stand naturally and barefoot on a hard platform in the upright position, with both ankles touching. Changes in vertical forces were applied to the platform and were recorded as changes in electric signals while the patient maintained a 30-sec upright stance. Body sway was assessed by instantaneous fluctuations in the center of pressure, namely, the sway path of the center of pressure which was designated as a statokinesigram. The present stabilometric measurements consisted of a standard test battery, and real-time calculations were carried out by the software installed in the Gravicorder GC-11 [5, 7].

The main parameters considered here were the length (LNG), which was defined as the linear length (cm) of the sway path in 30 sec; the area enveloped (ENV-AREA), which was defined as the area (cm^2) surrounded by the outermost reach of the sway path; the rectangular area (REC-AREA), which was defined as the area (cm^2) of a rectangle which fit into the outermost reach of the sway path. The other parameters were as follows: the root mean square area (RMS-AREA, cm^2); the length in a particular unit of time (LNG/TIME, cm/second), as calculated by division of the length by the time; LNG/ENV-AREA (1/cm) as calculated by division of the length by the area enveloped. The center of pressure was

Table 1 Clinical data of 28 patients with strabismus tested by stabilometry

Case No./Age(year)/Sex	Diagnosis	Best-corrected visual acuity		TNO stereoacuity (seconds)	Bagolini striated glasses test		Abnormal head posture	Surgical procedure	
		R.E.	L.E.		at 5 m	at 0.3 m			
1/5/Female	XpT	1.0	2.0	60	R) suppression	fusion	No	R) LR recess R) MR resect	6 mm 6 mm
2/7/Female	XpT	1.0	1.0	60	L) suppression	fusion	No	L) LR recess L) MR resect	6 mm 6 mm
3/10/Female	XpT	2.0	2.0	60	R) suppression	L) suppression	face turn to L 5°	R) LR recess R) MR resect	8 mm 8 mm
4/7/Male	XpT	1.5	1.5	60	R) suppression	fusion	No	R) LR recess R) MR resect	7 mm 7 mm
5/8/Male	L) Duane syndrome	1.5	1.2	No	fusion	fusion	face turn to L 15°	L) MR recess	6 mm
6/7/Female	XpT	1.5	1.5	60	R) suppression	fusion	No	R) LR recess R) MR resect	5 mm 5 mm
7/6/Male	XpT	1.5	1.5	60	L) suppression	L) suppression	No	L) LR recess L) MR resect	7 mm 7 mm
8/9/Male	L) SO palsy	0.7	1.0	No	R) suppression	fusion	No	L) IO recess	
9/6/Female	ET	2.0	1.2	No	fusion	L) suppression	No	L) MR recess L) LR resect	3 mm 4 mm
10/5/Female	ET	1.2	1.5	No	R) suppression	R) suppression	No	R) MR recess R) LR resect	4 mm 6 mm
11/5/Female	B) IO-OA	0.8	1.2	No	R) suppression	R) suppression	face turn to L 10°	B) IO recess	
12/9/Male	XpT	2.0	2.0	30	R) suppression	fusion	No	R) LR recess R) MR resect	8 mm 8 mm
13/10/Female	ET	1.5	1.5	No	L) suppression	L) suppression	No	L) MR recess L) LR resect	3.5 mm 7 mm
14/7/Female	XT	0.5	1.5	No	R) suppression	R) suppression	No	R) LR recess R) MR resect	7 mm 7 mm

15／10／Male	XpT	1.2	1.5	60	L) suppression	L) suppression	No	L) LR recess L) MR resect	9 mm 9 mm
16／ 9／Male	B) SO palsy after R) IO recess	1.2	2.0	No	R) suppression	L) suppression	face turn to L 15° head tilt to R 15° chin elevation 15°	L) IO recess	
17／12／Female	XpT	1.5	1.5	120	R) suppression	fusion	No	R) LR recess R) MR resect	6 mm 6 mm
18／10／Male	XpT	1.0	1.5	60	fusion	fusion	No	L) LR recess L) MR resect	6 mm 6 mm
19／ 6／Female	Secondary XT B) IO-OA, DVD after B) MR recess for Infantile ET	1.2	1.2	No	R) suppression	R) suppression	chin depression 10° head tilt to L 10° face turn to R 10°	B) IO recess R)MR advance	
20／ 4／Male	Residual ET after L) MR recess for ET	1.0	0.8	No	L) suppression	L) suppression	face turn to R 15°	L) LR recess	6 mm
21／11／Male	XT	2.0	2.0	No	R) suppression	R) suppression	head tilt to L 5°	R) LR recess R) MR resect	9 mm 8 mm
22／ 5／Female	L) SO palsy	1.5	1.5	120	L) suppression	fusion	head tilt to R 25°	L) IO recess	
23／ 7／Male	Part. Acc. ET	1.0	0.9	No	R) suppression	R) suppression	No	L) MR recess L) LR resect	3 mm 7 mm
24／ 6／Male	ET	1.2	1.5	No	R) suppression	R) suppression	No	R) MR recess R) LR resect	3 mm 7 mm
25／ 9／Female	XpT	1.5	1.5	60	R) suppression	fusion	No	R) LR recess R) MR resect	5 mm 5 mm
26／ 6／Female	XpT	1.5	1.2	No	L) suppression	L) suppression	face turn to L 10°	L) LR recess L) MR resect	6 mm 6 mm
27／ 8／Male	XpT	2.0	2.0	60	fusion	fusion	No	L) LR recess L) MR resect	6 mm 6 mm
28／ 3／Male	XpT L) IO-OA	0.9	0.9	No	R) suppression	R) suppression	No	B) LR recess L) IO recess	7 mm

DVD, dissociated vertical deviation; ET, esotropia; IO, inferior oblique muscle; IO-OA, inferior oblique muscle overaction; LR, lateral rectus muscle; MR, medial rectus muscle; Part Acc. ET, partially accommodative esotropia; SO palsy, superior oblique muscle palsy; XpT, intermittent exotropia; XT, exotropia.

considered as the mean of the fluctuations observed in 30 sec and was expressed as deviations along the X axis and Y axis (positive to negative numbers in cm) from the theoretical center of both feet (mean of X and mean of Y).

The measurements took place in a room with white walls that was illuminated under conditions of uniform brightness. After each patient had stood on the platform for 7 sec, he or she underwent a round of tests, which consisted of measurements of body sway with the patient's eyes open for 30 sec, followed by a 30-sec interval, and then the measurements of body sway were repeated with the patient's eyes closed for 30 sec. The patients underwent this round of tests twice and the second set of data was used for the statistical analysis. The light source used as a visual target was placed 1.5 m from the patients and was fixed on the wall at a height that corresponded to the center of the neck of each patient. The patients were instructed to look at the light source while the measurements were carried out with the patients' eyes open. An examiner stood outside the visual field of the patients, *i.e.*, typically behind the patients.

Clinical factors and statistical analysis. Before surgery, stereoacuity at 0.3 m was measured by the TNO Test for Stereoscopic Vision (Lameris Ootech B.V., Veenendaal, The Netherlands), whereas near and distant peripheral fusion with a visual target placed at 0.3 m and 5 m, respectively, was evaluated by the Bagolini striated glasses test. Abnormal head posture was assessed under natural conditions associated with observing an object, and the results were documented by an examiner. The patients were divided into 2 groups based on the presence or absence of measurable stereoacuity (480 sec of arc or better, versus no stereoacuity), peripheral fusion (fusion either at 0.3 m or at 5 m or both, versus suppression both at 0.3 m and at 5 m), and abnormal head posture. The stabilometric parameters of both groups before strabismus surgery were compared by the Mann-Whitney U-test. The preoperative and postoperative parameters were also compared in each patient using the Wilcoxon signed ranks test. These comparisons were carried out for a total of 28 patients, and separately, for a subgroup of 16 patients with exotropia.

Results

Pre- versus post-operative stabilometric parameters in a total of 28 patients. Fig. 1 shows an example of the stabilometric measurements made before and after inferior oblique muscle recession in a 9-year-old boy with congenital superior oblique muscle palsy on the left side (Case 8). Among a total of 28 patients, the values of 5 stabilometric parameters (the linear length of the sway path, the linear length of the sway path in time, the enveloped, rectangular, and root mean square areas) were found to significantly increase after strabismus surgery compared with the preoperative values, thus indicating that body sway became significantly more pronounced after the surgery ($p < 0.05$, Wilcoxon signed ranks test, Table 2). The increase in post-surgery body sway was observed under both conditions examined, *i.e.*, when the patient's eyes were open, as well as when the eyes were closed. A Romberg quotient of each stabilometric parameter, *i.e.*, the ratio of the parameter obtained with the patient's eyes open and that obtained with the patient's eyes closed, did not reveal any significant differences between the values obtained postoperatively and preoperatively.

Among a total of 28 patients, the center of pressure, which was expressed as the mean of the deviation along the X axis and the mean of the deviation along the Y axis (mean of X and mean of Y), did not change significantly according to a comparison of the preoperative and postoperative values (Wilcoxon signed ranks test, Table 2 and Fig. 1). However, an exception was observed in one patient (Case 19), who exhibited marked displacement of the center of pressure after surgery (Fig. 2). This 6-year-old girl underwent a second surgery to treat her secondary exotropia following the initial surgery for infantile esotropia. In general, no relationship was identified between the types of strabismus and the deviation of the center of pressure before and after surgery.

Pre- versus post-operative stabilometric parameters in 16 patients with exotropia. In a subgroup of 16 patients with exotropia under the eyes-open condition (for an example, see Fig. 3), the values of 4 stabilometric parameters (the linear length of the sway path, the linear length of the sway path in a particular unit of time, the enveloped area, and the root mean square area) significantly increased

Table 2 Stabilometric parameters (range with a median) in a total of 28 patients with different types of strabismus before and after strabismus surgery

	Before surgery		After surgery		Wilcoxon signed ranks test
With eyes open					
Length (cm)	38.14–78.87	(56.87)	29.85–120.62	(67.72)	0.0008
Length / Time (cm/second)	1.27–2.62	(1.90)	0.3–4.02	(2.24)	0.0059
Length / Enveloped area (cm^{-1})	8.36–32.73	(15.81)	6.73–27.38	(15.02)	0.4255
Enveloped area (cm^2)	1.28–7.93	(3.50)	1.09–15.82	(5.08)	0.0031
Rectangular area (cm^2)	3.16–18.68	(8.47)	3.14–40.44	(13.6)	0.0033
Root mean square area (cm^2)	0.72–6.51	(2.14)	0.60–8.13	(3.24)	0.0043
Mean of X	−1.23–1.23	(0.02)	−1.18–10.85	(−0.45)	0.7498
Mean of Y	−6.04–1.47	(−2.50)	−9.99–2.67	(−3.10)	0.1718
With eyes closed					
Length (cm)	46.38–146.98	(79.79)	49.80–175.82	(92.77)	0.0067
Length / Time (cm/second)	1.54–4.89	(2.66)	1.66–5.86	(3.09)	0.0067
Length / Enveloped area (cm^{-1})	6.77–20.84	(16.19)	7.18–25.96	(13.71)	0.3055
Enveloped area (cm^2)	2.66–11.70	(5.47)	2.32–15.76	(7.36)	0.0055
Rectangular area (cm^2)	5.56–32.43	(14.87)	6.48–62.27	(20.14)	0.0148
Root mean square area (cm^2)	1.53–9.18	(3.30)	1.53–10.40	(4.26)	0.0305
Mean of X	−1.29–1.10	(0.01)	−1.67–11.03	(0.02)	0.8376
Mean of Y	−6.16–1.15	(−2.02)	−10.05–2.00	(−2.76)	0.2455

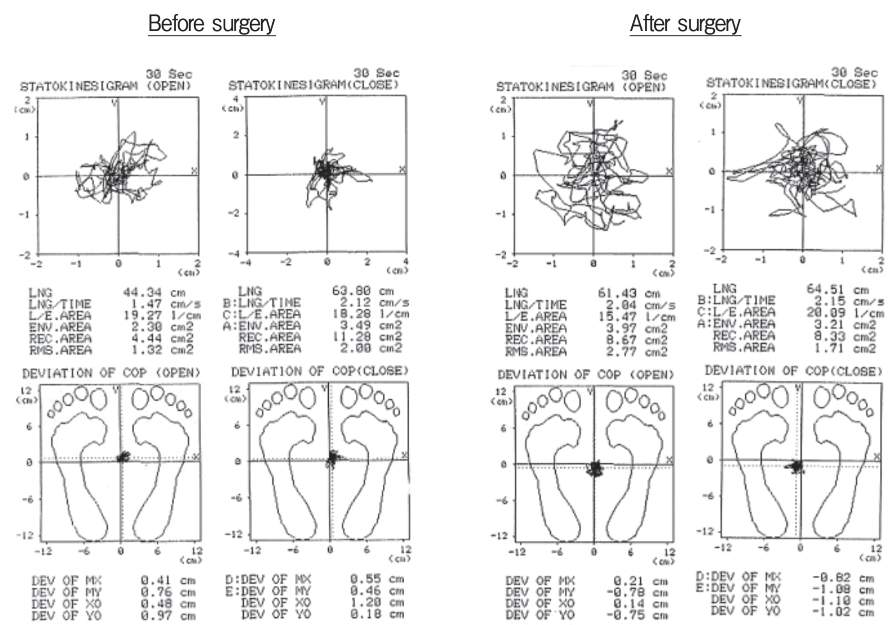

Fig. 1 Stabilometric measurements with the patient's eyes open and with the patient's eyes closed before and after strabismus surgery in a 9-year-old boy with left superior oblique muscle palsy (Case 8). The center of pressure fluctuated more after strabismus surgery than before the surgery. Note the lack of change in the center of pressure itself.

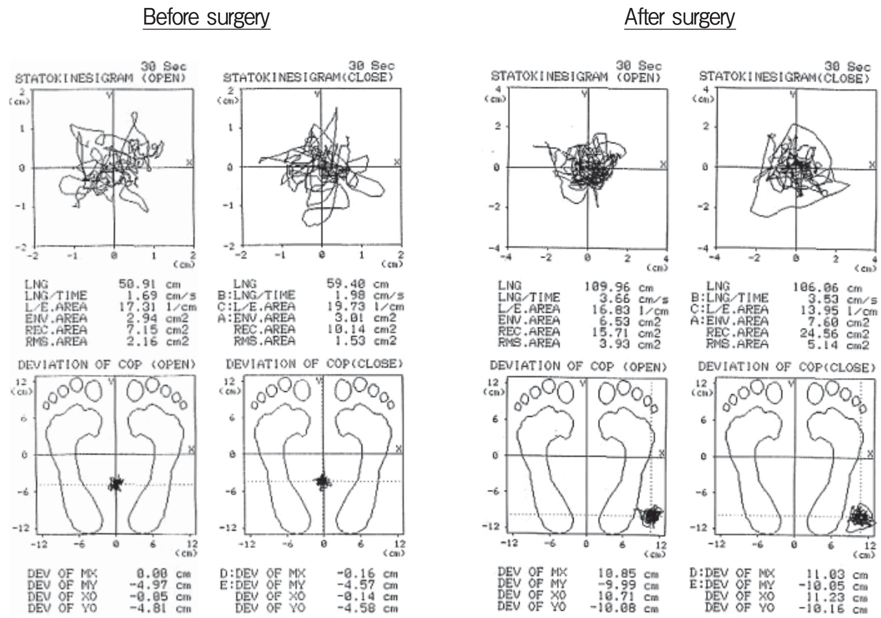

Fig. 2 Stabilometric measurements with the patient's eyes open and with the patient's eyes closed before and after strabismus surgery in a 6-year-old girl with secondary exotropia following a previous surgery for infantile esotropia (Case 19). Note the marked displacement of the center of pressure after strabismus surgery, as compared to the preoperative center.

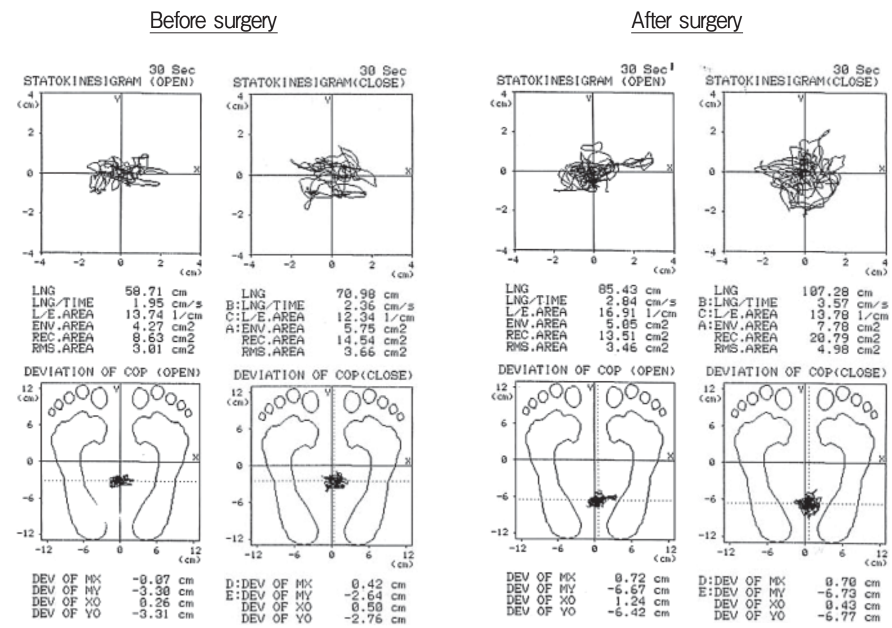

Fig. 3 Stabilometric measurements with the patient's eyes open and with the patient's eyes closed before and after strabismus surgery in a 7-year-old boy with intermittent exotropia (Case 4). The center of pressure fluctuated to a greater extent postoperatively than preoperatively under both conditions, *i.e.*, eyes open and eyes closed. Note also the postoperative deviation of the center of pressure toward the heel.

after strabismus surgery, compared with the values of the preoperative parameters, thus indicating that the magnitude of body sway increased significantly after surgery in this subgroup of 16 patients as well as was observed in the general group of 28 patients ($p < 0.05$, Wilcoxon signed ranks test, Table 3). The postoperative increase in body sway was also observed when the patients had their eyes closed (Table 3). In addition, the center of pressure along the Y axis of orientation from the toe to the heel (mean of Y) among patients with exotropia showed significant deviation toward the heel under both conditions of the eyes open and eyes closed, after surgery, as compared with the preoperative measurements ($p < 0.05$, Wilcoxon signed ranks test, Table 3 and Fig. 3). In contrast, the preoperative and postoperative measurements did not significantly differ with respect to the center of pressure along the X axis (mean of X; Table 3 and Fig. 3).

Preoperative stabilometric parameters and clinical factors in a total of 28 patients. Before surgery, 15 patients with an absence of TNO stereoacuity exhibited more body sway, as demonstrated by 2 parameters (Length and Length/Time), than 13 patients with measurable TNO stereoacuity, under the eyes-open condition ($p < 0.05$, Mann-Whitney U-test, Table 4). Under both conditions, *i.e.*, eyes open and eyes closed, 15 patients with an absence of peripheral fusion had a more deviated center of pressure along the Y axis oriented from the toe to the heel ($p < 0.05$, Mann-Whitney U test, Table 4), than 13 patients with peripheral fusion. Furthermore, 9 patients with abnormal head posture showed a more deviated center of pressure along the Y axis than 19 patients without abnormal head posture under the eyes-closed condition ($p = 0.017$, Table 4).

Preoperative stabilometric parameters and clinical factors in 16 patients with exotropia. In the subgroup of 16 patients with exotropia before the surgery, 3 patients with abnormal head posture showed a greater extent of body sway under the eyes-open condition, as demonstrated by one parameter (Length/Enveloped area), than 13 patients who did not exhibit abnormal head posture ($p = 0.0186$, Mann-Whitney U-test, Table 5). The presence or the absence of TNO stereoacuity and peripheral fusion did not correlate with the extent of body sway before surgery in this subgroup of 16 patients with exotropia (Table 5).

Discussion

In this pilot study, we measured postural instability in terms of body sway in children with different

Table 3 Stabilometric parameters (median with range) before and after strabismus surgery in a subgroup of 16 patients with exotropia

	Before surgery	After surgery	Wilcoxon signed ranks test
With eyes open			
Length (cm)	50.03 (38.14–78.26)	66.10 (29.85–120.62)	0.0113
Length / Time (cm/second)	1.66 (1.27–2.60)	2.20 (0.99–4.02)	0.0131
Length / Enveloped area (cm^{-1})	16.07 (8.36–32.73)	15.21 (10.02–27.38)	0.6051
Enveloped area (cm^2)	3.34 (1.28–6.48)	4.15 (1.09–8.31)	0.0151
Rectangular area (cm^2)	8.02 (3.16–18.27)	10.37 (3.14–25.91)	0.0557
Root mean square area (cm^2)	1.91 (0.72–6.51)	2.61 (0.60–6.06)	0.0437
Mean of X (cm)	−0.04 (−1.23–0.76)	−0.04 (−0.92–1.67)	0.4690
Mean of Y (cm)	−1.99 (−6.04–1.47)	−3.23 (−7.48–1.92)	0.0340
With eyes closed			
Length (cm)	79.79 (46.38–121.23)	92.37 (60.24–138.74)	0.0494
Length / Time (cm/second)	2.66 (1.54–4.04)	3.08 (2.00–4.62)	0.0494
Length / Enveloped area (cm^{-1})	15.65 (6.77–20.84)	13.71 (7.18–25.96)	0.6791
Enveloped area (cm^2)	5.79 (2.66–11.70)	6.94 (2.32–13.05)	0.0318
Rectangular area (cm^2)	15.96 (5.56–31.86)	19.32 (6.48–31.24)	0.0980
Root mean square area (cm^2)	3.49 (1.81–9.18)	4.11 (1.53–10.40)	0.1961
Mean of X (cm)	−0.05 (−1.29–1.05)	−0.03 (−1.163–1.52)	0.5520
Mean of Y (cm)	−1.70 (−5.55–1.15)	−2.76 (−7.65–1.19)	0.0299

types of strabismus standing naturally before and after strabismus surgery. The postoperative measurements were carried out on the 3rd day after surgery, when eye irritation caused by the surgical procedures had almost resolved, and the effect of general anesthesia had become negligible. This is the first study to measure body sway both preoperatively and postoperatively in patients who underwent strabismus surgery.

The reason for choosing children with exotropia

Table 4 Preoperative stabilometric parameters (range with a median) in relation with the presence or the absence of preoperative TNO stereoacuity, peripheral fusion, and abnormal head posture in a total of 28 patients with different types of strabismus

	Length (cm)	Length/Time (cm/second)	Length/Enveloped area (cm^{-1})	Enveloped area (cm^2)	Rectangular area (cm^2)	Root mean square area (cm^2)	Mean of X (cm)	Mean of Y (cm)
Preoperative with eyes open								
TNO stereoacuity								
No (n = 15)	41.90–78.87 (60.12)	1.39–2.62 (2.00)	9.88–32.73 (14.82)	1.28–7.93 (4.20)	3.16–18.68 (10.12)	0.72–5.06 (2.48)	−1.23–1.23 (0.03)	−6.01–1.23 (−2.81)
Yes (n = 13)	38.14–58.71 (49.56)	1.27–1.95 (1.65)	8.36–22.70 (15.93)	1.68–6.48 (3.20)	5.08–18.27 (8.08)	1.32–6.51 (1.86)	−0.95–0.96 (0)	−6.04–1.47 (−2.29)
P value	0.0226	0.0239	0.5042	0.0621	0.2221	0.1067	0.9816	0.6286
Peripheral fusion								
Yes (n = 13)	38.14–75.74 (50.50)	1.27–2.52 (1.66)	12.77–22.70 (15.69)	1.68–5.93 (3.32)	4.44–16.57 (8.21)	1.32–3.66 (1.95)	−0.95–0.96 (0)	−5.94–1.47 (−1.05)
No (n = 15)	41.90–78.87 (57.32)	1.39–2.62 (1.91)	8.36–32.73 (15.93)	1.28–7.93 (3.96)	3.16–18.68 (9.71)	0.72–6.51 (2.37)	−1.23–1.23 (0.03)	−6.04–1.23 (−3.33)
P value	0.2401	0.2788	0.5963	0.2222	0.5962	0.2133	0.7297	0.0177
Abnormal head posture								
No (n = 19)	38.14–78.26 (56.41)	1.27–2.60 (1.88)	8.36–22.70 (15.69)	1.68–6.48 (3.68)	4.44–18.27 (8.52)	1.32–6.51 (2.11)	−0.95–1.23 (0.14)	−4.96–1.47 (−2.12)
Yes (n = 9)	41.90–78.87 (58.46)	1.39–2.62 (1.94)	9.94–32.73 (17.31)	1.28–7.93 (3.20)	3.16–18.68 (7.88)	0.72–5.06 (2.16)	−1.23–0.96 (−0.11)	−6.04–−0.09 (−3.33)
P value	0.3893	0.4167	0.6403	0.7492	0.8248	0.9804	0.7122	0.0520
Preoperative with eyes closed								
TNO stereoacuity								
No (n = 15)	51.38–146.98 (89.82)	1.71–4.89 (2.99)	8.77–20.84 (16.27)	3.01–11.18 (4.95)	6.67–32.43 (12.92)	1.53–6.33 (2.83)	−1.18–0.74 (−0.08)	−5.76–1.15 (−2.10)
Yes (n = 13)	46.38–119.22 (79.31)	1.54–3.97 (2.64)	6.77–19.11 (15.70)	2.66–11.70 (5.75)	5.56–31.86 (15.49)	1.81–9.18 (3.52)	−1.29–1.10 (0.08)	−6.16–−0.09 (−1.59)
P value	0.6617	0.6617	0.3450	0.5042	0.4202	0.3218	0.8178	0.6286
Peripheral fusion								
Yes (n = 13)	46.38–146.98 (79.31)	1.54–4.89 (2.64)	6.77–19.11 (16.64)	2.66–11.70 (5.41)	5.56–31.86 (14.54)	1.81–9.18 (3.52)	−1.29–1.10 (0.16)	−6.16–0.46 (−0.60)
No (n = 15)	47.15–135.14 (80.26)	1.57–4.50 (2.67)	7.84–20.84 (16.10)	3.01–11.18 (5.52)	6.67–32.43 (15.19)	1.53–6.33 (2.95)	−1.18–1.05 (−0.17)	−5.76–1.15 (−2.72)
P value	0.6954	0.6954	0.8719	0.7297	0.7646	0.8538	0.4200	0.0177
Abnormal head posture								
No (n = 19)	46.38–121.23 (79.31)	1.54–4.04 (2.64)	6.77–19.93 (16.27)	2.66–11.70 (5.52)	5.56–31.86 (15.49)	1.81–9.18 (3.14)	−1.29–0.74 (0.08)	−4.69–1.15 (−1.59)
Yes (n = 9)	51.38–146.98 (80.26)	1.71–4.89 (2.67)	10.28–20.84 (16.10)	3.01–11.18 (4.75)	8.57–32.43 (12.41)	1.53–6.33 (3.52)	−1.18–1.10 (−0.18)	−6.16–−0.49 (−3.49)
P value	0.5716	0.5716	0.9412	0.8248	0.6759	0.6938	0.8247	0.0170

The presence of peripheral fusion with a visual target placed either at 0.3 m or at 5 m or at both determined by Bagolini striated glasses test is designated as "Yes". "No" means the absence of peripheral fusion both at 0.3 m and at 5 m. *P* values are for Mann-Whitney U-test.

as a subgroup in the present study was that the number of children with exotropia was sufficiently large for statistical analysis. Exotropia has been the dominant form of strabismus in recent years in Japan, as compared with the less dominant esotropia [16]. Children, especially those with intermittent exotropia, usually undergo strabismus surgery at older ages, albeit while still children, and those with infantile esotropia typically undergo the surgery at an earlier age. Both groups studied here, *i.e.*, the total

Table 5 Preoperative stabilometric parameters (median with range) in relation with the presence or the absence of preoperative TNO stereoacuity, peripheral fusion, and abnormal head posture in a subgroup of 16 patients with exotropia

	Length (cm)	Length / Time (cm/second)	Length/ Enveloped area (cm^{-1})	Enveloped area (cm^2)	Rectangular area (cm^2)	Root mean square area (cm^2)	Mean of X (cm)	Mean of Y (cm)
Preoperative with eyes open								
TNO stereoacuity								
No (n = 4)	65.75	2.19	19.42	3.98	9.00	2.32	−0.23	−1.99
	(41.90–78.26)	(1.39–2.60)	(11.92–32.73)	(1.28–4.73)	(3.16–10.66)	(0.72–2.83)	(−1.23–0.72)	(−2.81–1.23)
Yes (n = 12)	49.25	1.65	15.81	3.20	8.02	1.81	−0.04	−1.81
	(38.14–58.71)	(1.27–1.95)	(8.36–22.70)	(1.68–6.48)	(5.08–18.27)	(1.32–6.51)	(−0.95–0.76)	(−6.04–1.47)
P value	0.1822	0.1816	0.3320	0.4669	0.8082	0.6274	0.8084	0.7160
Peripheral fusion								
Yes (n = 9)	47.47	1.65	15.69	3.32	8.08	1.86	−0.70	−1.32
	(38.14–58.71)	(1.27–1.95)	(13.74–22.70)	(1.68–4.27)	(5.08–8.73)	(1.32–3.01)	(−0.95–0.38)	(−3.30–1.47)
No (n = 7)	54.18	1.80	17.86	3.58	7.88	2.26	0.21	−2.12
	(41.90–78.26)	(1.39–2.60)	(8.36–32.73)	(1.28–6.48)	(3.16–18.27)	(0.72–6.51)	(−1.23–0.76)	(−6.04–1.23)
P value	0.2664	0.3401	0.6338	0.4273	0.8738	0.6718	0.4273	0.3683
Abnormal head posture								
No (n = 13)	50.50	1.66	15.69	3.35	8.21	1.95	−0.70	−1.32
	(38.14–78.26)	(1.27–2.60)	(8.36–22.70)	(1.68–6.48)	(5.08–18.27)	(1.32–6.51)	(−0.95–0.38)	(−3.55–1.47)
Yes (n = 3)	49.56	1.65	20.97	2.24	5.57	1.45	0.72	−2.81
	(41.90–75.08)	(1.39–2.50)	(19.98–32.73)	(1.28–3.58)	(3.16–7.88)	(0.72–2.26)	(−1.23–0.76)	(−6.04–−1.86)
P value	0.9464	>0.9999	0.0186	0.1578	0.0509	0.1575	0.3819	0.1578
Preoperative with eyes closed								
TNO stereoacuity								
No (n = 4)	84.78	2.82	15.50	5.16	13.11	2.80	−0.64	−1.87
	(64.79–121.23)	(2.15–4.04)	(13.06–20.84)	(3.86–8.51)	(8.57–23.83)	(2.37–5.30)	(−1.18–0.51)	(−2.77–1.15)
Yes (n = 12)	79.79	2.66	15.65	5.81	16.37	3.56	0.08	−1.50
	(46.38–119.22)	(1.54–3.97)	(6.77–19.11)	(2.66–11.70)	(5.56–31.86)	(1.81–9.18)	(−1.29–1.05)	(−5.55–−0.09)
P value	0.7160	0.7160	0.5443	0.5443	0.4669	0.4669	0.4295	0.9035
Peripheral fusion								
Yes (n = 9)	79.31	2.64	15.70	5.75	15.49	3.52	0.80	−1.39
	(46.38–119.22)	(1.54–3.97)	(6.77–19.11)	(2.66–11.70)	(5.56–31.86)	(1.81–9.18)	(−1.29–0.42)	(−2.64–0.09)
No (n = 7)	80.26	2.67	14.24	5.83	16.43	3.46	−0.17	−1.93
	(47.15–121.23)	(1.57–4.04)	(7.84–20.84)	(3.86–8.51)	(8.57–23.83)	(2.37–5.30)	(−1.18–1.05)	(−5.55–1.15)
P value	0.9578	0.9578	0.7913	0.7913	0.9578	0.8738	0.7908	0.2235
Abnormal head posture								
No (n = 13)	79.31	2.64	15.60	5.83	17.24	3.52	−0.17	−1.41
	(46.38–121.23)	(1.54–4.04)	(6.77–19.11)	(2.66–11.70)	(5.56–31.86)	(1.81–9.18)	(−1.29–0.42)	(−2.64–1.15)
Yes (n = 3)	80.26	2.67	16.75	4.48	9.78	2.83	0.51	−2.77
	(64.79–93.40)	(2.15–3.11)	(13.69–20.84)	(3.86–5.86)	(8.57–15.19)	(2.37–5.14)	(−1.18–1.05)	(−5.55–−1.80)
P value	0.9464	0.9464	0.3130	0.2012	0.0693	0.6377	0.3119	0.0511

The presence of peripheral fusion with a visual target placed either at 0.3 m or at 5 m or at both determined by Bagolini striated glasses test is designated as "Yes". "No" means the absence of peripheral fusion both at 0.3 m and at 5 m. *P* values are for Mann-Whitney U test.

of 28 patients and the subgroup of 16 patients with exotropia, showed increased postural instability under both conditions studied, *i.e.*, eyes open and the eyes closed, after strabismus surgery, in comparison with the preoperative values.

A change in visual perception induced by surgical eye alignment may account for the observed increase in postural instability in the patients when their eyes were open after strabismus surgery. Concurrent with the results of this study, postural stability in the elderly has been shown to deteriorate due to the influence of refractive blur [17] and visual blur, the latter simulating the condition of cataract [18]. The visual acuity in both eyes of the children enrolled in this study was within the normal range and did not change after surgery, suggesting that changes in binocular vision might account for an increase in postural instability.

Postural instability was also found to increase after surgery, even under the eyes-closed condition. This finding suggests that factors other than visual input were altered by the surgery. One such candidate factor is the proprioception associated with the extraocular muscle. The extraocular muscle in humans has the structure of muscle spindles and innervated myotendinous cylinders [19–22], which are thought to participate in the proprioceptive regulation of the eye position. However, to date, there has been no direct evidence demonstrative of such proprioceptive control of the extraocular muscles; nonetheless, the role played by proprioception in the muscle has been clinically indicated on the basis of observations of psychophysical changes after strabismus surgery [23] and after botulinum toxin injection into the extraocular muscle [24]. Resection of the extraocular muscle would be expected to directly disturb the proprioceptive tissues, whereas recession of the muscle would also influence proprioception via changes in the muscle tension.

In a total of 28 patients involved in this study, no significant difference was observed between the preoperative and postoperative values of the Romberg quotient of each stabilometric parameter, which was the ratio of the parameter obtained with the patient's eyes open and that with the eyes closed. This finding suggests that some factor unrelated to whether the eyes were open or closed had changed after strabismus surgery. One candidate to account for the results in the present study would be the proprioception associated with the extraocular muscle, as discussed above. Furthermore, the center of pressure in the subgroup of 16 patients with exotropia deviated toward the heel under both conditions, *i.e.*, eyes open and closed, after strabismus surgery, as compared with the preoperative measurement, thus suggesting that surgery-induced changes in the proprioception of the extraocular muscle might also have altered the center of pressure. In contrast, no tendency toward change was observed in the preoperative and postoperative patterns of the center of pressure in patients with other types of strabismus. It remains unknown why the center of pressure deviated toward the heel in the patients with exotropia examined here.

This study also revealed that body sway before surgery was greater in patients with poor stereoacuity than in patients with good stereoacuity under the eyes-open condition. Furthermore, the deviation of the center of pressure along the Y axis was larger in patients with an absence of peripheral fusion under both conditions, *i.e.*, eyes open and eyes closed. These results suggest that TNO stereoacuity and peripheral fusion, as indicators of binocular function, exert effects on postural control and positioning.

In a total of 28 patients with strabismus before surgery, the center of pressure deviated more in patients with abnormal head posture than in patients with normal head posture, when under the eyes-closed condition. Furthermore, in the subgroup of 16 patients with exotropia, body sway before surgery was more pronounced in patients with abnormal head posture than in those with normal head posture, when under the eyes-open condition. Based on these findings, it appears that abnormal head posture exerts an influence on postural positioning and stability, as would be expected. Abnormal head posture is occasionally observed in patients with strabismus, and usually manifests as a compensation for strabismus itself, as well as for nystagmus, blepharoptosis, and uncorrected refractive errors [25]. From the perspective of attaining postural stability, it is of value to perform strabismus surgery in these patients in addition to maintain or restore normal binocular function and to restore the head posture to normal.

In conclusion, we demonstrated in this pilot study that postural instability increased immediately after strabismus surgery. It remains unknown whether or not such postural instability will persist in these patients. Such changes could be temporary after strabismus surgery, since sensory adaptation usually takes place in situations involving postural control. In addition, the effects of general anesthesia could not be completely excluded on the third day after surgery. In future studies, it will be necessary to perform stabilometric measurements 2 months or more after strabismus surgery. This study also provided support for the notion that abnormal head posture influences postural stability and positioning before surgery. Using a new stabilometric technique, body sway measurements may provide information for the elucidation of the systemic effects of strabismus, and thus help us gain a better understanding of the pathological mechanisms associated with strabismus.

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