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Seizure-like activities in patients with head-up tilt test-induced syncope

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Abstract

The purpose of this study was to assess the prevalence and the characteristics of seizure-like activities during head-up tilt test (HUT)-induced syncope, in patients with suspected vasovagal syncope (VVS). We also evaluated the differences in hemodynamic parameters between patients with and without seizure-like activities.

A total of 71 patients with suspected VVS, who showed syncope during HUT between October 2010 and May 2013, were analyzed. Electrocardiogram and hemodynamic parameters were continuously monitored during HUT. We also performed video recording of patients during HUT to identify eyeball deviation or seizure-like limb movements.

In all, 47 patients (66.2%) showed seizure-like activities at the time of syncope during HUT, 14 patients presented eyeball deviation, without abnormal limb movements, and 33 patients showed abnormal limb movements, such as myoclonic or tonic-clonic activities, as well as eyeball deviation. Upon comparison of the 2 groups with or without seizure-like activities, patients showing seizure-like activities presented a significantly lower heart rate at the time of syncope in HUT (38.51 ± 16.81 vs 49.67 ± 20.12, $P < .05$). Also, upon comparison within patients showing seizure-like activities, the patients who showed abnormal limb movements with eyeball deviation demonstrated a significantly lower systolic blood pressure and cardiac output at the time of syncope (34.30 ± 12.24 vs 49.00 ± 14.14, $P < .05$; 0.58 ± 0.40 vs 1.32 ± 0.97, $P < .05$).

Seizure-like activities were observed in high percentage in about 66% of patients during HUT-induced syncope. The occurrence of seizure-like activities was associated with more severe transient hemodynamic changes, such as lower heart rate, systolic blood pressure, and cardiac output at the time of the HUT-induced syncope.

Abbreviations: BRS = baroreflex sensitivity, EEG = electroencephalogram, HUT = head-up tilt test, PI = pulse interval, SBP = systolic blood pressure, VVS = vasovagal syncope, xBRS = cross-correlation baroreflex sensitivity.

Keywords: head-up tilt test, seizure-like activity, vasovagal syncope

1. Introduction

Syncope is usually defined as a sudden, transient loss of consciousness as a result of cerebral hypoperfusion. About 1 million patients are evaluated for syncope annually in the United States. It has known that 3% to 5% of emergency department visits and 1% to 6% of hospital admissions are for evaluation of syncope.[1,2] Vasovagal syncope (VVS) is the most common type of syncope, and it has been estimated that up to 40% of syncopal episodes evaluated in the outpatient clinic are VVS.[1]

VVS is characterized by excessive vagal tone and sympathetic withdrawal.[3–5] It was well-known that patients with VVS could often present seizure-like activities, such as eyeball deviation or abnormal limb movements, during syncopal episodes.[6,7] Therefore, many patients with VVS accompanied with seizure-like activities were misdiagnosed as epilepsy, and led to taking unnecessary antiepileptic drugs.[6,8] Although there were several studies that analyzed about seizure-like activities accompanying during syncope, each researcher showed a large difference for the prevalence and the type of seizure-like activities during syncope. The prevalence of seizure-like activities in studies using head-up tilt test (HUT) was reported to vary from 8% to 66% though there was some difference on the protocol of HUT.[6,9,10] Also, the reports about the hemodynamic parameters associated with seizure-like activities during syncope were inconsistent. HUT has been proposed as a useful tool to confirm VVS in suspected cases.[5,11]

The purpose of our study is to assess the prevalence and the characteristics of seizure-like activities during HUT-induced syncope in patients with suspected VVS. We have also evaluated any differences in hemodynamic parameters during HUT between patients with and without seizure-like activities.

2. Methods

2.1. Study populations

A total of 2169 consecutive patients with suspected VVS, underwent HUT at Samsung Medical Center, Seoul, Korea from

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October 2010 to May 2013. Of these patients, 1328 patients showed a positive response to HUT. A positive response of HUT was defined as follows: when syncope or presyncope was shown in association with hypotension (systolic blood pressure [SBP] <80 mm Hg), bradycardia (a sinus arrest >3 seconds or heart rate <45 beats/min the first phase, <60 beats/min in the second phase), or both.[5,12,13]

Among 1328 patients, 74 patients experienced syncope during HUT, and did not have any other cause of syncope. Of these 74 patients, 3 patients were excluded from the study because there was incomplete data about the hemodynamic parameter during HUT. Therefore, the data of 71 patients were finally analyzed. This study was approved by the Regional Committee for Ethics in Medical Research (IRB No. 2015-08-013).

2.2. Head-up tilting test

HUT was conducted on patients who had fasted at least 4 hours. We have used the HUT protocol, which has been reported previously.[14] After 10 minutes of rest period in supine position, the patients were tilted to 70° on an electric tilt table with foot plate support and body straps for up to 30 minutes or until positive responses appeared. If the first phase of HUT was negative, the second phase, with isoproterenol infusion, was started while patients were kept in the same 70° upright posture as in the first phase. Isoproterenol was intravenously administered at an initial rate of 1 μg/min. The infusion rate was increased by 1 μg/min every 3 minutes, to a maximum of 5 μg/min. When positive response was observed during the HUT, or the study end point was reached, tilting table was rapidly lowered to horizontal position. During the HUT, cardiac rhythm continuously monitored and blood pressure, heart rate, cardiac output, peripheral resistance, and baroreflex sensitivity (BRS) were noninvasively measured with a photoplethysmograph (Finometer PRO, Finapres Medical Systems B.V., Amsterdam, The Netherlands). BRS was measured using the cross-correlation baroreflex sensitivity (xBRS) method.[15] The xBRS method is as follows: The SBP and pulse interval (PI) time series were spline interpolated and resampled at 1 Hz. In 10-second windows, correlation and regression slopes between SBP and PI were computed. Delays of 0- to 5-second increments in PI were computed, and the delay with the highest positive coefficient of correlation was selected; the optimal delay (τ) was also stored. The slope between SBP and PI was recorded as an xBRS estimate if the correlation was significant at $P < .01$. If these conditions were not met, there was no result for this time segment.[15,16]

To define the differences in hemodynamic parameters according to seizure-like activities, hemodynamic parameters at 3 different time points during HUT were analyzed: at 5 minutes in supine position before the first phase, at 10 minutes in 70° upright posture after the start of the first phase, and the time when syncope occurs. As in the previous study, the pattern of a positive response of HUT was classified as follows: vasodepressive type, cardioinhibitory type, and mixed type.[12,13] The vasodepressive type was defined as a drop in the SBP <80 mm Hg without a significant drop in the heart rate. The cardioinhibitory type was defined as a sinus arrest (>3 seconds) or bradycardia (<45 beats/min in the first phase, <60 beats/min in the second phase). The mixed type was defined as the occurrence of both hypotension and bradycardia. Also, the presence of asystole was defined as a pause lasting longer than 3 seconds, was measured.

2.3. Video recording in HUT

To define the prevalence and the type of seizure-like activity during syncope more accurately, we conducted video recording using closed-circuit television (SRD-470D, Samsung Techwin, Seoul, Korea) during HUT. The camera was located on the ceiling at front side of patient to record seizure-like activities, such as eyeball deviation or limb movement. After HUT, video records were reviewed by 2 neurologists repeatedly to achieve consensus regarding seizure-like activities that happened during HUT-induced syncope.

2.4. Seizure-like activities during HUT-induced syncope

Seizure-like activities were defined as eyeball deviation or limb movement, such as myoclonic or tonic-clonic activity of limbs, during HUT-induced syncope. Myoclonus was defined as abrupt, brief, and shock-like muscle activation, and tonic-clonic activity was defined as tonic spasm with or without clonic movement on limbs. The patients were classified into 3 groups according to their appearance during HUT-induced syncope. Patients without seizure-like activities such as eyeball-deviation or limb movements, and patients showing both eyeball deviation and limb movements.

2.5. Statistical analysis

Means were calculated for continuous variables, and the frequency was measured for categorical variables. Comparisons were made by Mann–Whitney test, and the chi-squared test was used for categorical variables. A P value $< .05$ was considered significant statistically. Data were analyzed with SPSS (SPSS Interactive Graphics, Version 20.0, SPSS Inc, Chicago, IL).

3. Results

3.1. The patients characteristics and the results of HUT

A total of 71 patients (32 men, 39 women; mean age 35.08 ± 1.77) were analyzed. The mean frequency of syncope before HUT was 3.15 ± 0.61 times. Over 27 patients (38.0%) suffered physical injury during syncope, and 68 patients (95.8%) experienced prodromal symptoms before syncopal episode. In terms of underlying disease, 9 patients (12.7%) suffered from hypertension, and 1 patient (1.4%) suffered from diabetes mellitus (Table 1). On the performed HUT, 23 patients (32.4%) presented syncope during the first phase without isoproterenol infusion, and 48 patients (67.6%) experienced syncope at the second phase with isoproterenol infusion. On the results of HUT, vasodepressive type was observed highest in 54 patients (78.9%),

Table 1

Baseline clinical characteristics of total patients (N = 71).

Variables	
Age, y	35.08 ± 1.77
Sex (male)	32 (45.1)
Frequency of syncope before diagnosis	3.15 ± 0.61
History of injury	27 (38.0)
Presence of prodromal symptom	68 (95.8)
Underlying disease	
None	61 (85.9)
Hypertension	9 (12.7)
Diabetes mellitus	1 (1.4)

Data are presented as the mean value ± standard deviation or number (%).

Table 2

The results of HUT in total patients (N = 71).

Variables	
Phase when syncope occurs during HUT	
First phase (without isoproterenol infusion)	23 (32.4)
Second phase (with isoproterenol infusion)	48 (67.6)
Duration of HUT, min	30.48 ± 1.34
Results of HUT	
Vasodepressive	54 (78.9)
Cardioinhibitory	2 (2.8)
Mixed	15 (18.3)

Data are presented as the mean value ± standard deviation or number (%).
HUT = head-up tilt test.

then mixed type in 15 patients (18.3%), and cardioinhibitory type was seen in 2 patients (Table 2).

3.2. Seizure-like activities during HUT

A high degree of interobserver agreement was found in the evaluation of seizure-like activities during HUT-induced syncope ($\kappa = 0.681$). A total of 47 patients (66.2%) showed seizure-like activities during HUT-induced syncope among 71 patients. In all, 24 patients (33.8%) collapsed flaccidly without seizure-like activities during HUT among 71 patients (Fig. 1). Of 47 patients who showed seizure-like activities, 14 patients (29.8%) only presented eyeball deviation, while 11 patients (23.4%) showed myoclonus plus eyeball deviation and 22 patients (46.8%) presented tonic-clonic activity plus eyeball deviation, respectively (Fig. 2).

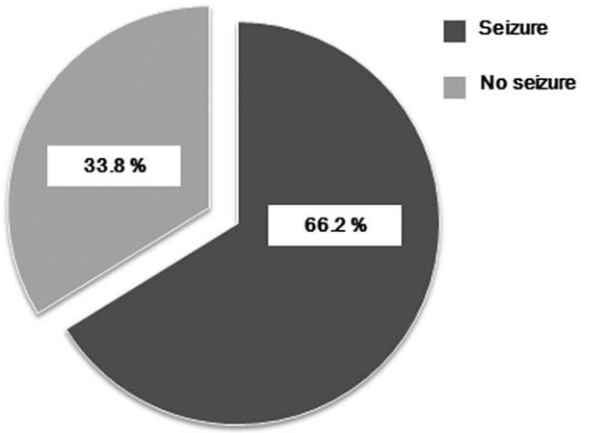

Figure 1. Incidence of seizure-like activities during head-up tilt test-induced syncope (N = 71).

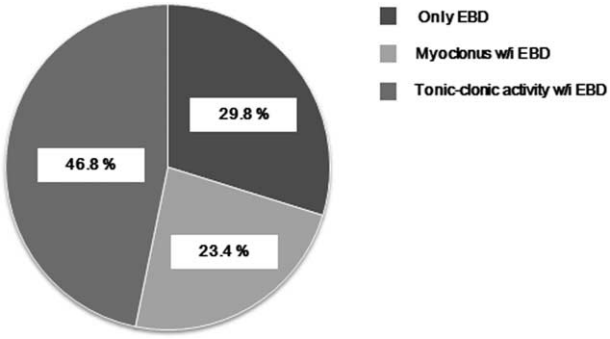

Figure 2. Pattern of head-up tilt test-induced seizure-like activities (N = 47). EBD = eyeball deviation, w/I, with.

3.3. Comparison of clinical characteristics and hemodynamic parameters between patients with and without seizure-like activities during HUT

There was no difference in age, gender distribution, or number of previous syncope between patients with and without seizure-like activities during HUT-induced syncope. Also, both groups showed similar history of physical injury from syncope and presence of prodromal symptoms (Table 3).

A comparison of the hemodynamic parameters revealed no significant difference in blood pressure, heart rate, cardiac output, peripheral resistance, or BRS that was observed in supine and standing position of HUT. However, patients showing seizure-like activities had a significantly lower heart rate at the time of syncope in HUT (38.51 ± 16.81 vs 49.67 ± 20.12, $P < .05$). Also, the proportion of cardioinhibitory or mixed pattern on the type of positive response in HUT was significantly higher in patients accompanied with seizure-like activities ($P < .05$). Five patients presenting seizure-like activities showed asystole at the time of syncope in HUT, although this was not statistically significant between the 2 groups ($P > .05$).

3.4. Comparison of clinical characteristics and hemodynamic parameters between patients with abnormal limb movement with eyeball deviation and those with only eyeball deviation during HUT-induced syncope

Upon comparison between patients showing seizure-like activities, the proportion of female was significantly higher in patients that showed abnormal limb movements with eyeball deviation, compared with those with only eyeball deviation. However, no significant difference was observed in age, number of previous syncope, history of physical injury from syncope, and presence of prodromal symptoms between the 2 groups (Table 4).

Also, there was no difference in the hemodynamic parameters between groups in the supine and standing position of HUT. However, patients presenting abnormal limb movement with eyeball deviation demonstrated a significantly lower SBP and cardiac output at the time of syncope (34.30 ± 12.24 vs 49.00 ± 14.14, $P < .05$; 0.58 ± 0.40 vs 1.32 ± 0.97, $P < .05$). There was no statistically significant difference in term of the proportion of vasodepressive, cardioinhibitory, or mixed pattern within the results of HUT between the groups ($P > .05$). Additionally, it was not statistically significant on the presence of asystole between the 2 groups, despite the fact that all 5 patients showed asystole at the time of syncope in HUT accompanied by abnormal limb movements with eyeball deviation ($P > .05$).

4. Discussion

In this study, seizure-like activities during HUT-induced syncope were observed in patients with a very high proportion (66.2%), and 14 patients (29.8%) of those 47 patients presented only eyeball deviation without abnormal limb movement, while 33 patients (70.2%) showed abnormal limb movements, such as myoclonic or tonic-clonic activities with eyeball deviation. The patients showing seizure-like activities had a significantly lower heart rate at the time of syncope in HUT. Also, the group showing seizure-like activities had a significant higher proportion of

Table 3

Comparison of clinical characteristics and hemodynamic parameters between patients without and with seizure-like activities during head-up tilt test-induced syncope.

Groups	No seizure-like activities (N = 24)	Seizure-like activities (N = 47)	*P*
Clinical characteristics			
Age, y	34.21 ± 15.98	35.26 ± 14.15	>.05
Sex (male)	9 (37.5)	23 (48.9)	>.05
Frequency of syncope before diagnosis	4.38 ± 8.17	2.53 ± 2.39	>.05
History of injury	9 (37.5)	18 (38.3)	>.05
Presence of prodromal symptom	22 (91.7)	46 (97.9)	>.05
Hemodynamic parameters			
Supine			
SBP, mm Hg	114.08 ± 11.92	115.94 ± 15.29	>.05
DBP, mm Hg	59.72 ± 10.74	65.05 ± 12.02	>.05
HR, bpm	66.86 ± 7.99	68.11 ± 14.47	>.05
CO, L/min	5.68 ± 1.83	5.61 ± 1.31	>.05
PR, mm Hg s/mL	0.94 ± 0.25	0.97 ± 0.27	>.05
BRS, ms/mm Hg	16.00 ± 14.24	15.15 ± 9.67	>.05
Standing, 10 min			
SBP, mm Hg	110.01 ± 14.51	110.21 ± 21.14	>.05
DBP, mm Hg	68.11 ± 10.94	70.50 ± 11.68	>.05
HR, bpm	86.12 ± 11.68	83.61 ± 14.02	>.05
CO, L/min	4.76 ± 1.08	4.73 ± 1.20	>.05
PR, mm Hg s/mL	1.12 ± 0.24	1.19 ± 0.36	>.05
BRS, ms/mm Hg	7.61 ± 6.34	6.90 ± 3.57	>.05
Syncope			
SBP, mm Hg	42.83 ± 10.48	36.68 ± 14.39	>.05
DBP, mm Hg	27.13 ± 8.52	23.09 ± 10.46	>.05
HR, bpm	**49.67 ± 20.12**	**38.51 ± 16.81**	**<.05**
CO, L/min	1.02 ± 0.89	0.80 ± 0.73	>.05
PR, mm Hg s/mL	3.88 ± 3.14	5.07 ± 6.85	>.05
BRS, ms/mm Hg	2.55 ± 2.89	2.61 ± 1.91	>.05
Asystole provoked	0 (0.0)	5 (10.6)	>.05
Vasodepressive pattern	**23 (95.8)**	**31 (65.9)**	**<.05**
Cardioinhibitory pattern	**0 (0.0)**	**2 (4.3)**	
Mixed pattern	**1 (4.2)**	**14 (29.8)**	

Data are presented as the mean value ± standard deviation or number (%). $P < 0.05$ was considered as statistically significant. Statistically significant values were bold-emphasized.
BRS = baroreflex sensitivity, CO = cardiac output, DBP = diastolic blood pressure, HR = heart rate, PR = peripheral resistance, SBP = systolic blood pressure.

cardioinhibitory or mixed pattern on the type of positive response in HUT, and showed asystole more frequently at the time of syncope in HUT. By contrast, the group presenting abnormal limb movement with eyeball deviation demonstrated a significantly lower SBP and cardiac output at the time of syncope than those with only eyeball deviation.

Our study identified that seizure-like activities, such as eyeball deviation or abnormal limb movement, accompanied syncope very frequently. It was considered that this high incidence of seizure-like activities during HUT-induced syncope was possible due to video recording during HUT test, and reviewing seizure-like activities that occurred during HUT-induced syncope. Lin et al also reported that, while the incidence of convulsive movement during syncope was 11.9% in retrospective analysis, the incidence of seizure-like limb movements during syncope was increased to 41.6% in prospective analysis for blood donors.[17] As with our results, Grubb et al reported the induction of syncope with tonic-clonic seizure-like activity using HUT in 66.7% patients with recurrent, unexplained seizure-like episodes, who were unresponsive to antiepileptic medication.[6] Lempert et al provoked syncope in 42 of 59 healthy control subjects using a combination of hyperventilation, orthostasis, and Valsalva maneuver, and they found that myoclonic activity occurred in 38 of those 42 subjects (90%).[7] As failure to identify VVS as the cause of seizure-like activities may lead to treatment that are ineffective and potential harmful, the physicians should be aware that seizure-like activities could be accompanied at a very high rate when syncope happened.[10,18]

Although seizure-like activities that occur during VVS may look similar to epileptic seizures, the mechanism of the development of seizure-like activities in syncope was known to be different from those of epileptic seizure. On electroencephalograms (EEGs) of patients with epileptic seizure, seizure-like activity is accompanied with epileptiform discharges, such as spike, sharp wave, or spike-and-slow complexes. However, nonepileptiform theta and delta wave slowing during VVS were seen contrast to epileptic seizure in a study performing simultaneous EEG during HUT.[19] Ammirati et al reported that diffuse slowing without spike or spike-wave activity during HUT-induced syncope was observed.[20] Also, more profound hemodynamic changes, such as asystole, can cause EEG flattening.[21,22] van Dijk et al demonstrated that every patient during syncope showed either a "slow-flat-slow" or "slow" pattern on the EEG.[21] EEG flattening, that is considered as a sign of more severe cerebral hypoperfusion, was known to be associated with generalized and sustained tonic contractures.[21,22] The underlying pathophysiology of seizure-like activity is thought to be related the inhibitory actions of hypoxia

Table 4

Comparison of clinical characteristics and hemodynamic parameters between patients with only eyeball deviation and those with both abnormal limb movement and eyeball deviation during head-up tilt test-induced syncope.

Groups	Only eyeball deviation (N = 14)	Abnormal limb movement with eyeball deviation (N = 33)	*P*
Clinical characteristics			
Age, y	35.00 ± 12.49	35.37 ± 14.97	>.05
Sex (male)	**10 (71.4)**	**12 (36.4)**	**<.05**
Frequency of syncope before diagnosis	2.14 ± 2.38	2.70 ± 2.40	>.05
History of injury	5 (35.7)	13 (39.4)	>.05
Presence of prodromal symptom	13 (92.9)	33 (100.0)	>.05
Hemodynamic parameters			
Supine position			
SBP, mm Hg	108.68 ± 8.85	119.02 ± 16.47	>.05
DBP, mm Hg	59.23 ± 8.27	67.52 ± 12.60	>.05
HR, bpm	63.07 ± 7.42	70.25 ± 16.22	>.05
CO, L/min	5.92 ± 1.43	5.48 ± 1.25	>.05
PR, mm Hg s/mL	0.84 ± 0.20	1.02 ± 0.28	>.05
BRS, ms/mm Hg	19.09 ± 9.98	13.48 ± 9.18	>.05
Standing, 10 min			
SBP, mm Hg	105.75 ± 7.93	112.10 ± 24.58	>.05
DBP, mm Hg	65.63 ± 6.32	75.58 ± 12.84	>.05
HR, bpm	80.90 ± 10.24	84.76 ± 15.34	>.05
CO, L/min	5.18 ± 1.23	4.54 ± 1.16	>.05
PR, mm Hg s/mL	0.96 ± 0.22	1.27 ± 0.38	>.05
BRS, ms/mm Hg	7.38 ± 2.77	6.69 ± 3.88	>.05
Syncope			
SBP, mm Hg	**49.00 ± 14.14**	**34.30 ± 12.24**	**<.05**
DBP, mm Hg	28.71 ± 10.00	20.70 ± 9.84	>.05
HR, bpm	45.93 ± 16.98	35.36 ± 15.96	>.05
CO, L/min	**1.32 ± 0.97**	**0.58 ± 0.46**	**<.05**
PR, mm Hg s/mL	3.67 ± 3.92	5.67 ± 7.75	>.05
BRS, ms/mm Hg	2.44 ± 1.11	2.69 ± 2.20	>.05
Asystole provoked	0 (0.0)	5 (15.2)	>.05
Vasodepressive pattern	12 (85.7)	19 (57.6)	>.05
Cardioinhibitory pattern	0 (0.0)	2 (6.0)	
Mixed pattern	2 (14.3)	12 (36.4)	

Data are presented as the mean value ± standard deviation or number (%).

BRS = baroreflex sensitivity, CO = cardiac output, DBP = diastolic blood pressure, HR = heart rate, PR = peripheral resistance, SBP = systolic blood pressure.

in the telencephalon and other cortical structures.[23,24] This inhibition leads to unopposed activation of the subcortical structures, in particular the brainstem reticular formation, resulting in sustained tonic contractures.[23] For the reasons described above, seizure-like activities during VVS could not be controlled by an antiepileptic drug, but rather the maneuvers to alleviate hemodynamic dysfunction can be effective to prevent the development of seizure-like activities during syncope.[10]

In this study, we also evaluated whether there is difference on clinical feature and hemodynamic parameters according to seizure-like activities that occurred during syncope. Several previous studies regarding the association between HUT-induced seizure-like activities and hemodynamic parameters did not show consistent results. Passman et al demonstrated that patients with tonic-clonic seizure-like activity had a significantly lower SBP at the time of termination of HUT. Also he found that heart rate at the time of termination of HUT was significantly slower in patients showing neurological events, such as focal seizures, dysarthria, aphasia, unilateral limb dysesthesia, or tonic-clonic seizure than in patients with no neurological events, and the occurrence of asystole was more common in patients presenting neurological features during HUT.[9] By contrast, Song et al reported that the seizure-like activities during syncope might not be associated with the severity of the clinical feature and hemodynamic parameters during HUT, and that cerebral autoregulation in response to hemodynamic dysfunction might play an important role in provoking seizure-like activities during HUT-induced syncope.[25] Stern and Tzivoni also reported that a patient with prolonged sinus arrest of 19 seconds felt only dizziness without seizure-like activities.[26]

In our study, seizure-like activities during HUT-induced syncope were more associated with a lower heart rate than a lower blood pressure. The proportion of cardioinhibitory or mixed patterns on the type of positive response was significantly higher in patients accompanied with seizure-like activities during HUT-induced syncope, and asystole occurred only in patients showing seizure-like activities. These findings could suggest that patient presenting cardioinhibitory or mixed response to HUT would experience with more severe transient hemodynamic changes at the time of the HUT-induced syncope. These findings could mean that not only asystole but also arrhythmia such as bradycardia could be more dangerous to brain when syncope happened.[27] By contrast, lower SBP and cardiac output at syncope were seen to be the more important factors regarding abnormal limb movements, consistent with previous studies.[9,21] In a study using EEG during HUT, seizure-like limb movements, such as myoclonic jerks or tonic-clonic activity, were observed more frequently upon flattening of the EEG.[21] Considering our

results together with these, the more severe transient cerebral hypoperfusion is thought to be associated with seizure-like limb movements, such as myoclonic or tonic-clonic activity of limbs, during syncope. We also measured cardiac BRS. BRS is known to be the amount of response in heart rate internally to a change in blood pressure, and is a prognostic factor of heart disease. However, there was no significant difference in BRS observed between groups with or without seizure-like activity in our study. These findings might be thought to be caused by the fact that all patients in our study presented syncope in HUT regardless of whether or not syncope was accompanied by seizure-like activities, and as such the value of BRS was relatively very low.

In our study, the proportion of females was found to be significantly higher in patients showing abnormal limb movements with eyeball deviation among patients presenting seizure-like activities, and those patients presented a significantly lower SBP and cardiac output at the time of syncope.

This study has several limitations. First, we only divided the patients showing seizure-like activities into 2 groups according to the presence of abnormal limb movement. Because it is relatively small patients, we did not observe the difference on the hemodynamic parameter when analyzing the groups in more detail according to the presence of myoclonus or tonic-clonic feature. Second, we did not perform either EEG or transcranial Doppler study to define the change in cerebral activity or perfusion during HUT, although we did measure the real-time hemodynamic parameters with video recording. Third, we did not conduct the studies such as the heart rate and heart rate variability before performing HUT. Those studies might be a parameter to predict arrhythmias and clinical events as index of autonomic dysfunction.[28]

In conclusion, seizure-like activities were frequently observed during HUT-induced syncope. The occurrence of seizure-like activities was associated with transient hemodynamic changes at the time of HUT-induced syncope.

Author contributions

Conceptualization: Byung-Euk Joo, Dae Lim Koo, Dae-Won Seo, June Soo Kim.
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Methodology: Byung-Euk Joo.
Supervision: Dae-Won Seo, June Soo Kim.
Validation: Byung-Euk Joo.
Writing – original draft: Byung-Euk Joo.

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