

The Role of the Capnography Head-up Tilt Test in the Diagnosis of Syncope in Children and Adolescents

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ABSTRACT. *Objectives.* To evaluate the role of the capnography head-up tilt test (CHUTT) in the diagnosis of syncope in pediatric patients.

Methods. The CHUTT is a head-up tilt test with concomitant capnometry. Hyperventilation on CHUTT was diagnosed when the patient's end-tidal carbon dioxide pressure (ETPCO₂) was ≤25 mm Hg. Hyperventilation syncope was diagnosed when three criteria were met: loss of consciousness, ETPCO₂ ≤25 mm Hg, and no significant drop in blood pressure. The cohort included 65 consecutive children and adolescents (mean age, 14.2 years) who were assessed for syncope by routine investigations and CHUTT.

Results. The cause of the syncope was established in 67% of cases: cardioinhibitory reaction in 17%, vasodepressor in 20%, psychogenic in 22%, and mixed neurally mediated-psychogenic in 8% of the patients. The history indicated a cause of syncope in 40%, the CHUTT in 49%, and a combination of the history and positive CHUTT in 66% of patients. Neither the patients' clinical data nor values of the blood pressure, heart rate, respiratory rate, and ETPCO₂ measured during recumbency predicted which patients would manifest hyperventilation or hyperventilation syncope on tilt.

Conclusions. The CHUTT contributes substantially to the diagnosis of syncope in pediatric patients. The CHUTT advances the understanding of the pathophysiological mechanisms of syncope and enables the physician to reassure the patient regarding the essentially benign nature of the condition. Because it is not possible to predict which patients would develop a hyperventilation syncope on the standard tilt test, the modification of this procedure by measuring the ETPCO₂ for the assessment of children with syncope should be considered. *Pediatrics* 1998;101(2). URL: <http://www.pediatrics.org/cgi/content/full/101/2/e6>; *syncope, pediatric, tilt test, capnography*.

ABBREVIATIONS. HUTT, head-up tilt test; CHUTT, capnography head-up tilt test; ETPCO₂, end-tidal carbon dioxide pressure; BP, blood pressure.

Syncope is one of the more common problems in pediatric practice and, although alarming when it occurs, is regarded as an essentially benign condition. Nevertheless, certain pathological entities, including some potentially dangerous ones, can present with syncope; therefore, it is important to consider which patients require further investigation.¹⁻⁶ The development of the head-up tilt test (HUTT) especially in adult medicine has contributed to our understanding of this condition.⁷

When a normal person stands, 10% to 15% of the blood is pooled in the legs reducing cardiac output and arterial pressure. The fall in pressure activates baroreceptors with a subsequent reflex increase in sympathetic outflow and parasympathetic inhibition, leading to peripheral vasoconstriction and increased heart rate and contractility. The blood pressure (BP) upon tilting returns to previous levels within 15 to 30 seconds and is maintained at an approximately constant level throughout the tilt, while the heart rate is slightly increased.⁸ The hemodynamic challenge caused by tilt may induce, in the predisposed patient, an anomalous response of the BP and heart rate. Furthermore, the tilt-induced hemodynamic challenge may induce, in the vulnerable patient, hyperventilation that results in hypocapnia with fatigue and impairment of consciousness.⁹ These symptoms can be explained primarily by diffuse cerebral vasoconstriction and ensuing cerebral hypoxia.^{10,11}

Recently a variant of the HUTT, the capnography head-up tilt test (CHUTT), has been proposed for the evaluation of syncope of undetermined cause in general and psychogenic syncope in particular.⁹ During the course of the CHUTT, in addition to the BP and heart rate, which is derived from the standard HUTT, the respiratory rate and end-tidal carbon dioxide pressure in the exhaled air (ETPCO₂) are continuously recorded. The purpose of this article is to describe the potential value of the CHUTT in the evaluation of syncope in the pediatric age group.

METHODS

Definitions

Syncope was defined as a transient loss of consciousness associated with loss of postural tone, occurring in the standing or sitting position and followed by a rapid spontaneous recovery on assuming the supine position. Presyncope was defined as a sensation of impending loss of consciousness, characterized by lightheadedness, dizziness, weakness, blurred vision, incoherence, slow response times to verbal stimuli, nausea, vomiting, or partial

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loss of postural tone.¹² Inclusion criteria for the cohort in this study were those patients manifesting either syncope or presyncope as defined above, and all patients were subsequently referred to under the term syncope. Cardiac and noncardiac causes of syncope were differentiated, and the following categories were diagnosed:⁷ 1) Neurally-mediated syncope, which results from reflex mechanisms that are associated with inappropriate vasodilatation, bradycardia, or both. The subtypes of neurally-mediated syncope are cardioinhibitory, vasodepressor, situational, and carotid sinus syncope. 2) Orthostatic hypotension that results either from autonomic insufficiency, volume depletion, medications, or advanced age-related physiologic changes. 3) Psychogenic syncope that is associated with anxiety, depression, or conversion disorders. A number of definitions of psychogenic syncope have been used by various authors, but all definitions include a loss or apparent loss of consciousness in the presence of a normal BP during the event.¹³ We diagnosed psychogenic syncope when at least one of the following criteria were met: 1) impaired consciousness associated with distinct hyperventilation was observed by the clinician before the CHUTT; 2) loss of consciousness, $\text{ETPCO}_2 \leq 25$ mm Hg, and no significant drop in BP on the CHUTT; and 3) a conversion reaction without hypocapnia was noted during the CHUTT. We therefore comprised within the category of psychogenic syncope different clinical syndromes, including hyperventilation syncope.

Population

Consecutive patients presenting with syncope or presyncope at the pediatric emergency room of the Bnai-Zion Medical Center from January 1, 1996, to December 31, 1996, were assessed prospectively and constituted the study group.

Basic Evaluation

The patients underwent a detailed history, a syncope questionnaire,¹⁴ a general physical examination, BP recorded in the recumbent and erect positions, laboratory tests (a complete blood count, electrolytes, glucose, blood urea nitrogen, and urinalysis), and a 12-lead electrocardiogram. The CHUTT was performed in all patients. Patients with abnormal findings on cardiac auscultation or electrocardiogram were evaluated by a pediatric cardiologist and underwent a 24-hour ambulatory electrocardiographic monitoring and echocardiography. An electroencephalogram was performed only when the possibility of a convulsive disorder was considered.

The CHUTT Protocol

The CHUTT is a modification of the HUTT consisting of concomitant continuous recording of the BP, heart rate, and ETPCO_2 . The BP was monitored using a mercury column sphygmomanometer with auscultatory BP readings by a physician. Heart rate was continuously recorded on an electrocardiogram monitor. The respiratory rate and the ETPCO_2 were continuously monitored with a Datex Normacap infrared capnometer (Normacap, Helsinki, Finland). Normal values of ETPCO_2 in our laboratory are within the range of 36 to 40 mm Hg. All parameters were recorded in the supine position for 10 minutes, and during head-up tilt to 70° for 30 minutes or until symptoms developed.¹⁵ The final readings in the supine position were compared with the final readings obtained during the tilt phase. Hyperventilation was diagnosed when the ETPCO_2 fell to 25 mm Hg or less. The 25 mm Hg cutoff, rather than the 30 mm Hg cutoff,^{16,17} was preferred because of the poor discriminatory power of the latter.¹⁸

Endpoints of the CHUTT

The following endpoints were observed:^{7,9,15,19}

Category A: syncope on tilt. 1) Orthostatic syncope was diagnosed when some degree of cerebral dysfunction and increase of heart rate of at least 10 beats per minute occurred during the first 3 minutes of the tilt associated with one or both of the following conditions: a fall of systolic BP of at least 20 mm Hg, and a fall of diastolic BP of at least 10 mm Hg compared with the last supine measurement. 2) Vasodepressor syncope was diagnosed when some degree of cerebral dysfunction and increase of heart rate of at least 10 beats per minute occurred after the initial 3 minutes of the tilt associated with a BP fall of a similar degree. 3) Cardioinhibitory syncope was diagnosed when a BP fall of a similar degree without an increase in heart rate was accompanied by some de-

gree of cerebral dysfunction. 4) Hyperventilation syncope was diagnosed when some degree of cerebral dysfunction occurred during tilt, associated with decrease of ETPCO_2 values to 25 mm Hg or less, unassociated with a fall in BP. 5) The term mixed hypotensive-hyperventilation syncope was defined as occurrence of some degree of cerebral dysfunction during tilt, associated with a decrease of ETPCO_2 values to 25 mm Hg or less, and a concomitant drop of systolic BP of 20 mm Hg or more, a drop of diastolic BP of 10 mm Hg or more, or both.

Category B: homeostatic abnormalities without a loss of consciousness. 1) cardioinhibitory reaction, 2) vasodepressor reaction, 3) hyperventilation reaction, and 4) mixed hypotensive-hyperventilation reaction.

The corresponding entities in category B differed from category A by being unassociated with impaired consciousness and postural tone.

Syncope Diagnosis

The diagnosis required that either 1) the syncopal episode was witnessed by a physician and examination during the syncope permitted an unequivocal diagnosis, or 2) when a spontaneous syncope was not witnessed by the physician, a diagnosis of syncope required that both the clinical history and results of syncope evaluation conformed to one of the established variants of syncope.⁷

Data Analysis

The patient files and the CHUTT records were reviewed by two independent physician evaluators. Complete agreement between them was required to classify the patients according to an etiological category. The following aspects were evaluated: 1) analysis of the etiologies of syncope and the contribution of diagnostic tests in establishing the diagnosis; 2) analysis of the endpoints reached on CHUTT; 3) examining the clinical factors that could predict pathological findings on the tilt test; and 4) scrutiny of CHUTT parameters during the supine phase (BP, heart rate, respiratory rate, and ETPCO_2) that could have predicted the occurrence of pathological features on tilt.

Statistical Analysis

The Kruskal-Wallis test or the *t* test were utilized as appropriate.²⁰

RESULTS

Sixty-five children and adolescents were evaluated, 21 males and 44 females, with a mean age of 14.2 years (standard deviation, 3.4; range, 6 to 17 years). During the year before the work-up a single syncopal episode had occurred in 21 cases, 2 to 4 episodes in 31 cases, and 5 or more episodes in 13 cases.

The etiologies of the syncope were as follows (Table 1): cardioinhibitory syncope in 11 patients (17%), vasodepressor syncope in 13 patients (20%), psychogenic syncope in 14 patients (22%), mixed hypotensive-psychogenic syncope in 5 patients (8%), and unknown in 22 patients (34%). Orthostatic syncope was not observed. Illustrative recordings are shown in Figures 1 and 2. A cardiac origin of the syncope was not revealed at initial work-up and follow-up in any of the 65 patients.

The history of the episode indicated a cause of syncope in 26 patients (40%), the physical examination in 3 patients (5%), when a cardioinhibitory faint or conversive reaction were witnessed by a physician, and the CHUTT in 34 patients (52%). When the history and data of the CHUTT were combined, the cause of syncope was established in 43 patients (66%) (Table 1). The various laboratory tests, electrocardiogram, echocardiography, and electroencephalogra-

TABLE 1. Causes of Syncope and Contribution of Diagnostic Tests to Their Diagnosis in 65 Patients

Causes of Syncope	Cardioinhibitory (n = 11)	Vasodepressor (n = 13)	Psychogenic (n = 14)	Mixed Hypotensive-Psychogenic (n = 5)	Total
History	10	8	5	3	26 (40%)
Physical examination	1*	0	2†	0	3 (5%)
CHUTT	2	13	14	5	34 (52%)
History and CHUTT	11	13	14	5	43 (66%)

* Loss of consciousness witnessed by the physician.

† Typical attack of a conversive reaction during the clinical examination.

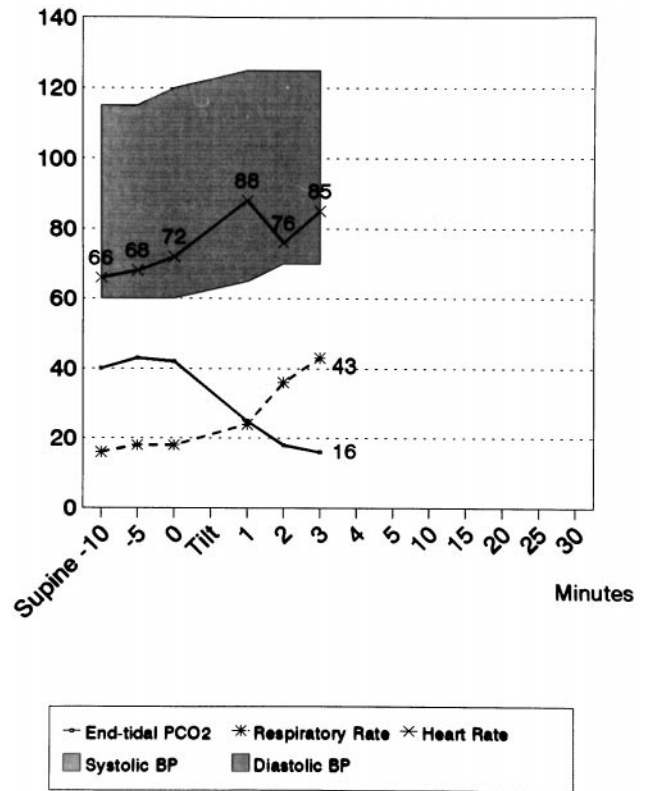
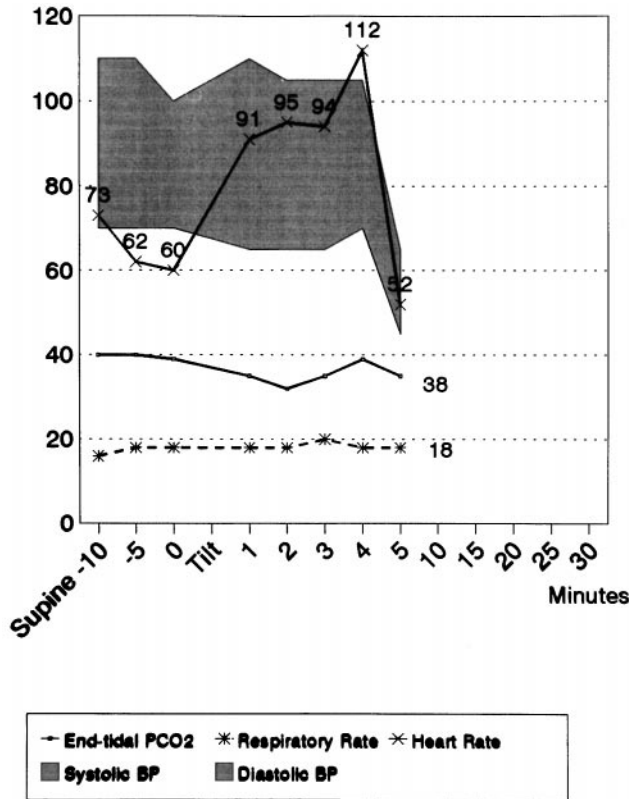


Fig 1. Cardioinhibitory syncope: during recumbency, the values of the blood pressure (BP), heart rate, respiratory rate, and ETPCO₂ were within normal limits. On the 5th minute of head-up tilt, the BP and heart rate abruptly decreased and the patient lost consciousness. The ETPCO₂ remained within normal range at the time of fainting.

Fig 2. Hyperventilation syncope: values of the blood pressure (BP) and heart rate were within the normal range during recumbency and tilt. The respiratory rate increased immediately after tilt, and the ETPCO₂ steeply decreased until the patient lost consciousness.

phy did not indicate the cause of the syncope in any of the patients.

Endpoints reached during the CHUTT are shown in Table 2. The CHUTT provoked impairment of the consciousness in 11 cases (17%) including cardioinhibitory syncope (n = 2), vasodepressor syncope (n = 1), hyperventilation syncope (n = 4), mixed cardioinhibitory-hyperventilation syncope (n = 1), mixed hypotensive-hyperventilation syncope (n = 1), and conversion reaction (n = 2). Homeostatic disturbances that were not associated with impairment of the consciousness were observed on CHUTT in 23 patients (35%): vasodepressor (n = 12), hyperventilation (n = 8), and mixed hypotensive-hyperventilation reaction (n = 3).

The patients' clinical data (age, gender, frequency of faints, apparent triggering factors of faints) as well as the CHUTT parameters during the supine phase were correlated with the occurrence of pathological

TABLE 2. Endpoints Reached on 65 CHUTT Examinations*

Endpoints	Cases	%
Impaired consciousness on tilt	11	17
Cardioinhibitory syncope	2	
Vasodepressor syncope	1	
Hyperventilation syncope	4	6
Mixed hypotensive-hyperventilation syncope	2	
Conversion reaction	2	
Not associated with impaired consciousness	23	35
Cardioinhibitory reaction	0	
Vasodepressor	12	18
Hyperventilation	8	12
Mixed hypotensive-hyperventilation reaction	3	

* More than one abnormality was observed in several patients.

features during tilt. None of the parameters were significantly associated with the pathological outcomes on tilt.

Furthermore, baseline-to-tilt changes of the heart rate, BP, respiratory rate, and ETPCO₂ were compared in three subgroups: patients with hyperventi-

lation on tilt (n = 12), patients with hypotension on tilt (n = 15), and patients who had neither hyperventilation nor hypotension on tilt (n = 33) (Table 3). It was shown that mean values recorded in the supine phase (BP, heart rate, respiratory rate, and ETPCO₂) were similar in the three subgroups and therefore could not predict the subsequent occurrence of specific homeostatic abnormalities on tilt.

DISCUSSION

The results of our investigation confirm the findings of earlier studies showing that cardioinhibitory, vasodepressor, and psychogenic syncope are the most frequent causes of transient loss of consciousness in childhood and adolescence.¹⁻⁵ A detailed history and the CHUTT were the most important instruments in establishing the cause of syncope.

Various protocols of upright tilt testing are currently in use such as different schemes of the passive HUTT and HUTT in conjunction with provocative agents.^{21,22} Review of the adult literature shows a mean percent of positive responses on the passive HUTT in 49% and specificity of 90%, contrasting with isoproterenol-enhanced HUTT with a mean percent of positive response of 66% and a specificity of only 55%.²¹ We therefore chose a passive HUTT protocol: this 10 minute supine-30 minute passive HUTT when combined with capnography was designated as the CHUTT. With the aid of the CHUTT, hypocapnia and occasionally hyperventilation syncope can be diagnosed.⁹

The pathophysiological mechanisms of the hyperventilation syncope are not completely understood. The trigger for spontaneous hyperventilation is not always obvious.¹⁸ The mechanism that links the hemodynamic challenge induced by tilt to the ensuing hyperventilation has also not been clarified. Two possible explanations are suggested. First, hyperventilation in this setting may be in fact a panic attack induced during tilt. However, full blown classic panic attacks are infrequently observed in the tilt laboratory. Second, hyperventilation may result from the triggering of the autonomic nervous system dur-

ing tilt, leading to activation of the respiratory center and hyperventilation. In support of this proposed mechanism is the observation that discontinuation of the tilt is usually followed by relief of the symptoms within 2 to 5 minutes.⁹ This may be consistent with a reflex mechanism rather than a psychogenic reaction. It is evident that activation of the autonomic nervous system during tilt may generate a mixture of ventilatory and hemodynamic reactions.

The impairment of consciousness, the final step in the chain of events, can be explained by more than one mechanism. Several hypothetical pathophysiological mechanisms for the hyperventilation syncope have been proposed. First, the hypocapnia resulting from hyperventilation can induce vasodilatation in muscles and subsequent hypotension, which can progress to syncope.²² Second, if hyperventilation is combined with a self-induced Valsalva's maneuver, the latter may play a role in the pathogenesis of syncope.²³ Third, in the absence of vasodepressor or a cardioinhibitory reaction, hypocapnia resulting from excessive expiratory loss of carbon dioxide can induce diffuse cerebral vasoconstriction and cause a loss of consciousness.^{10,11} Hypocapnia may occur jointly with hypotension, and both mechanisms may synergistically promote cerebral ischemia and subsequent syncope. It is noteworthy that at a given level of hypocapnia syncope will not always result.⁹ More than one pathophysiological mechanism may therefore be active in precipitating the syncope in a given hyperventilating anxious patient. These aberrant mechanisms can be demonstrated with the CHUTT.

The diagnosis of hyperventilation is not difficult when the patient presents with a history of a sudden onset of rapid deep breathing followed by lightheadedness, weakness, and tingling of the extremities. The clinical picture, in conjunction with absence of abnormal cardiac or pulmonary findings or hypoxia, and termination of the incident by rebreathing into a paper bag permit one to make an immediate diagnosis.²³ Frequently, however, the hyperventilation is not clinically obvious^{16-18,23} and neither the patient nor the physician is aware of a change in either the

TABLE 3. Comparison of Parameters of the Capnography Head-up Tilt Test in Three Subgroups*

Patients	Hyperventilation Mean (Standard Deviation) Group I (n = 12)	Hypotension Mean (Standard Deviation) Group II (n = 15)	Neither Hyperventilation nor Hypotension Mean (Standard Deviation) Group III (n = 33)	P Value
Supine†				
Heart rate (bpm)	75.4 (17)	79.9 (14.2)	79.4 (14.2)	NS
Systolic BP (mm Hg)	106.7 (15)	108.7 (11.9)	102.9 (10.7)	NS
Diastolic BP (mm Hg)	65.4 (9.4)	64.7 (6.4)	65.3 (5.7)	NS
Respiratory rate/min	17.3 (3.8)	16.9 (2.8)	16.5 (2.1)	NS
ETPCO ₂ (mm Hg)	36.4 (3.6)	38.3 (4.1)	39.3 (3.5)	NS
Tilt‡				
Heart rate (bpm)	101.3 (17.6)	102 (21.3)	108.7 (15.8)	NS
Systolic BP (mm Hg)	103.3 (13.5)	80.3 (14.6)	95.0 (10.9)	<.0001
Diastolic BP (mm Hg)	65.0 (9.8)	50.3 (10.1)	60.0 (6.7)	<.0001
Respiratory rate/min	28.1 (11.8)	20.0 (3.1)	18.0 (2.0)	<.0001
ETPCO ₂ (mm Hg)	21.0 (3.9)	34.7 (5.1)	35.9 (4.6)	<.0001
Duration of tilt (min)	23.8 (6.2)	25.9 (8)	29.1 (5.2)	=.05

* The three subgroups are patients with hyperventilation on tilt, patients with hypotensive events on tilt, and patients with neither hyperventilation nor hypotension on tilt. Excluded from analysis were 5 patients with mixed hypotension-hyperventilation on tilt.

† Values at the end of the supine phase.

‡ Peak abnormalities during the tilt phase.

depth or frequency of respiration. The giddiness, faintness, or lightheadedness that often accompany hyperventilation may persist for hours and sometimes days,²⁴ in contrast to the short duration of the syncope. Some authorities are of the opinion that hyperventilation probably does not cause a genuine syncope;^{23,25} however, this has been recently disputed.^{10,11,26} In the present study, out of 17 patients having hypocapnia on CHUTT, 4 patients had hyperventilation syncope and 2 had mixed hypotensive-hyperventilation syncope. The data provided by the CHUTT confirmed that an entity of hyperventilation syncope might exist.

The typical patient with hyperventilation syncope manifested features of a generalized anxiety disorder. Episodic losses of consciousness, sometimes associated with falls, occurred in clusters during a period of a few months. The triggering factor for the events varied in the same patient: from strenuous exertion to no apparent cause in most instances, such as relaxing seated on a chair. During rest it was not possible to predict which patients would develop a hyperventilation syncope on tilting (Table 3). Throughout the test the examiners were impressed by the patients' restlessness and anxiety, which was rarely noted in the other categories of patients. Pallor and excessive tachycardia occurred during the tilt phase. The respiratory rate was only slightly increased in most patients even at the time of severe hypocapnia so that the hyperventilation was not obvious. Hyperventilation syncope was alleviated within 2 to 5 minutes by retilting the patient to the supine position. Hyperventilation syncope differed from the conversion reaction observed on the tilt table in 2 patients. Conversion reactions presented shortly after securing the patient to the tilt table, while still in the supine position; they were not associated with hyperventilation and hypocapnia. Their duration was between 10 to 20 minutes, and they were not mitigated by loosening the security girdles and changing the patient's posture. Psychogenic syncope is, therefore, a comprehensive term including a variety of psychological and physiological reactions, one of those being hyperventilation syncope.

The reproducibility of hyperventilation and hyperventilation syncope was demonstrated in a previous study,⁹ in which the specificity of the CHUTT in the diagnosis of hyperventilation syncope in adults was 100%. In that study hyperventilation syncope occurred only in patients with recurrent spontaneous syncope, but not in the control patients without a history of syncope, including subgroups of patients with generalized anxiety disorder, chronic fatigue syndrome, and arterial hypertension.^{9,27}

The incidence of hyperventilation syncope has not been determined. This is attributable to the hitherto absence of accurate criteria for its diagnosis and a low index of suspicion for a relatively unknown condition. In early studies only rare mention of the psychological causes of syncope were noted.^{10,28,29} More recent surveys, however, mention an underlying psychological disorder in nearly one-third of unselected young patients who presented for an eval-

uation of syncope.^{1,30,31} Unfortunately, tilt tests were not done in these studies and the diagnosis of hyperventilation syncope was based on the much-criticized voluntary hyperventilation test.¹⁰ Neurally-mediated syncope was not distinguished from psychogenic syncope.³⁰ In a previous study of a highly selected adult population, including 14 patients who had both spontaneous syncope and syncope on a HUTT that was not associated with hypotension, repeated evaluation with the aid of the CHUTT showed hyperventilation in 11 (78%) and hyperventilation syncope in 7 (50%) of the cases.⁹ In a second group of 50 consecutive adults with syncope, the CHUTT revealed hyperventilation in only 5 patients (10%) but none had a hyperventilation syncope on tilt.⁹ In the present study in 65 consecutive pediatric patients with syncope, the CHUTT revealed hyperventilation in 17 patients (26%), of which 4 (6%) had genuine hyperventilation syncope and 2 (4%) had mixed hyperventilation-hypotensive syncope.

In conclusion, the CHUTT contributes substantially to the diagnosis of syncope in pediatric patients. The CHUTT advances the understanding of the pathophysiological mechanisms of syncope and enables the physician to reassure the patient regarding the essentially benign nature of the condition. Because it is not possible to predict which patients would develop a hyperventilation syncope on the standard tilt test, the modification of this procedure by measuring the ETPCO₂ for the assessment of children with syncope should be considered.

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