Hypocapnia and Its Relation to Fear of Falling

John E. Clague, MD, MRCP, Paula J. Petrie, MRCP, Michael A. Horan, PhD, FRCP

ABSTRACT. Clague JE, Petrie PJ, Horan MA. Hypocapnia and its relation to fear of falling. Arch Phys Med Rehabil 2000;81:1485-8.

Objective: To determine if hypocapnia occurs in patients with fear of falling and to explore potential causes of hypocapnia.

Design: Observational study in patients who fall with and without fear of falling.

Setting: Rehabilitation wards of an elderly care unit.

Patients: Consecutive fallers with ($n = 20$) and without ($n = 10$) fear of falling.

Main Outcome Measures: End-tidal CO_2 (P_{ETCO_2}) and respiratory rate (RR) responses were measured during sustained isometric muscle contraction (SIMC) (40% of maximum voluntary contraction of quadriceps for 2min) and during a 5-meter walk. Falls efficacy scale (FES) and Hospital anxiety and depression scale (HAD).

Results: Patients with fear of falling had significantly higher FES and HAD scores ($p < .01$). During SIMC, baseline and nadir P_{ETCO_2} levels were significantly lower in patients with a fear of falling ($p < .01$). During the 5-meter walk, P_{ETCO_2} was lower at baseline, at nadir, and at the end of the walk in the fear of falling group than in controls ($p < .01$). RR was higher at nadir and end of the walk in the fear of falling group than in controls ($p < .02$).

Conclusions: Hypocapnia may occur in patients with a fear of falling during SIMC and walking. Anxiety seems to be the main cause, but muscle weakness may contribute. Breathing or relaxation techniques and reconditioning may have a role in treating fear of falling in the rehabilitation setting.

Key Words: Anxiety; Hypocapnia; Isometric contraction; Muscle contraction; Rehabilitation.

THIRTY PERCENT of community-dwelling people over 65 years of age fall each year[1] and in controlled trials of the elderly seeking treatment at accident and emergency departments after falls, 65% reported falls in the previous year.[2] Typically, only falls leading to injury or loss of function are reported, hence, figures probably underestimate actual incidents. Fractures, soft tissue injury, joint dislocation, and mobility impairments occur in 15% to 20% of falls.[3]

The psychologic consequences of falls can be equally disabling. Fear of falling, even present in some nonfalling elderly, is reported to occur in up to 60% of fallers,[1,4,5] and one third of such patients report avoidance of activity after a fall.[1,5] Subsequently, limitation of activity may lead to physical deconditioning, functional deterioration, and actually increase fall risk and potential injury. Fear of falling is also associated with significant psychologic morbidity (high anxiety and depression scores are reported in community-dwelling patients with fear of falling).[6] It has also been proposed that fear of falling is a remediable independent contributor to functional decline.[7]

Fear of falling is frequently seen during rehabilitation after a fall and may delay progress and hospital discharge. Increased spontaneous sway and poor 1-leg stance are associated with fear of falling in balance tests.[8] Patients with fear of falling may adopt different balance strategies to cope. In balance studies, decreased stride length and speed as well as prolonged double support have been used as measures to combat fear of falling.[9]

In young normal patients, during sustained isometric muscle contraction (SIMC), marked hyperventilation may occur with marked falls in Pa_{CO_2}.[10-12] In turn, this may lead to a reduction in cerebral blood flow,[12] which may result in presyncopal symptoms and postural instability. In elderly patients, as a consequence of the decline in muscle strength with aging, many everyday activities, such as getting out of a chair, may require near maximal muscular effort. Hypocapnia may, therefore, occur during these activities and may contribute to unsteadiness and falls in frail patients. Many other symptoms can be associated with hypocapnia including dizziness, weakness, anxiety, and panic.[13] Anxiety itself may produce hyperventilation and hypocapnia. It is possible that hypocapnia occurs during mobilization after a fall because of the need for maximal muscle activation to stand and walk. It may occur as a feature of fear and anxiety or may induce the symptoms of anxiety and fear itself.

In this preliminary study, we wanted to determine if hypocapnia could be detected in elderly fallers. We also wanted to see whether it occurred during SIMC, in association with rising from a chair, or during walking, and whether it was particularly associated with reported fear of falling.

PATIENTS

Patients were recruited from admissions to rehabilitation wards at our hospital with falls (noninjurious, injurious). Consecutive fallers, who were cognitively intact (abbreviated mental test score > 7)[14] and were able to walk 5 meters with or without an aid, were invited to participate. Patients with known chronic obstructive pulmonary disease (COPD) or asthma were excluded. All patients were studied at the same time of day, at least 2 hours after their last meal. The study was approved by our hospital ethics committee. Patients with fear of falling were identified by their response to the question, "Do you have fear of falling?" Those answering yes were included in the fear of falling group; those answering no entered the control group.

Each group included injured and noninjured fallers. In the fear of falling group, 6 patients had sustained fractured neck of femur, 2 had humeral fractures, 1 had Colles' fracture, and the rest had no bony injury. In the control fallers, 5 had fractured neck of femur, 1 had a humeral fracture, and the rest had no bony injury. In the fear of falling group, 14 patients mobilized with walking frames and 6 with sticks. In the control fallers, 8 used walking frames and 2 used sticks. There were no other

From Geriatric Medicine, Clinical Division 1, University of Manchester, Manchester, UK.

Accepted in revised form March 28, 2000.

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the authors or upon any organization with which the authors are associated.

Reprint requests to John E. Clague, Geriatric Medicine, Clinical Sciences Bldg, Hope Hospital, Stott Ln, Salford M6 8HD, UK.

0003-9993/00/8111-5892$3.00/0

doi:10.1053/apmr.2000.9628

major comorbidities in the groups studied. Two patients in the fear of falling group and 1 in the control group had controlled hypertension. One patient in each group had well-controlled angina pectoris.

METHODS

Psychologic Assessment

In addition to the dichotomous question, "Do you have fear of falling?", patients were asked, "Have you avoided activities because of fear of falling?" Under supervision, patients also completed the falls efficacy scale (FES),[4] which is a 10-item scale developed to measure fear of falling. Each item is scored from 1 (very confident, no fear of falling) to 10 (very fearful of falling). The scale is reported to be valid and reliable.[4] The hospital anxiety and depression (HAD) scale was administered under supervision.[15] This is a 14-item scale for use with medically ill, hospitalized patients to assess levels of anxiety and depression. Each item is rated from 0 to 3, and the scale is reported to be valid and reliable.[15] Patients were asked to indicate their pain level immediately before the study using a 10-cm visual analog scale (VAS); a score of 0 indicating no pain and a score of 10 indicating the worse pain ever experienced.

Muscle Function

Maximal voluntary contraction. Maximal isometric strength of the patient's preferred or noninjured quadriceps femoris muscle was measured with the knee at 90° using a portable pressure transducer[a] as per manufacturer's instructions. The transducer was attached to a chair and to the patient's ankle via an inextensible strap. The best recording of at least 5 measurements with a 1-minute rest between recordings was taken after a training period.

Sustained isometric contraction. Patients were asked to maintain 40% of their maximum velocity contraction (MVC) for a 2-minute period. Patients watched an LED display of force generation to maintain target force. End-tidal CO_2 ($PETCO_2$) and respiratory rate (RR) were measured by using a soft plastic cannula taped at the nostril entrance using a Datex Normocap 200 infrared CO_2 meter[b] calibrated as per the manufacturer's instructions. This device gives a breath-by-breath display of RR and $PETCO_2$ and CO_2 waveform. This recording method has been reported to give technically satisfactory data.[17]

After baseline recordings, RR and $PETCO_2$ were recorded. Nadir value of $PETCO_2$ and associated RR during SIMC was also recorded.

Stand and 5-Meter Walk

The procedure was explained to patients before test commencement. With the cannula in place, basal recordings of $PETCO_2$ and RR were made after a 5-minute rest period. Patients were asked to stand up and walk for 5 meters and then to sit again, at their own pace. An investigator walked alongside the patient with the CO_2 analyzer on a trolley. Another investigator walked alongside each patient in case of overbalancing and falls. At the end of each walk, patients rested for 5 minutes. $PETCO_2$ and RR were recorded immediately on standing, nadir $PETCO_2$ and associated RR were recorded during walking, and values immediately on sitting and after 3 minutes' rest were also recorded. At least 2 walks were performed in each patient.

Statistical Analysis

Statistical analyses were performed using a commercially available statistical package.[c] Normally distributed data were compared using nonpaired Student t tests, and Mann-Whitney U tests were used for nonnormally distributed data. The relation between variables were examined using least squares regression analysis.

Table 1: Patient Characteristics

	Fear of Falling	Controls
Subjects (n)	18 women/2 men	8 women/2 men
Age (yr)	80.7 ± 5.1	81.7 ± 6.5
Time from fall (d)	23.2 ± 16	23.9 ± 17
Pain score (VAS) (cm)	1.4 ± 1.8	1.7 ± 2
MVC (N)	140 ± 68	149 ± 57
FES	60 ± 12	18 ± 10*
HAD scale	14.5 ± 6.5	6 ± 3.4*
Anxiety component of HAD scale	8.4 ± 3.7	4.2 ± 3.3*
Do you have fear of falling? (Y/N)	20/0	0/10
Have you avoided activities through fear of falling? (Y/N)	14/6	0/10

Values shown as mean ± SD.
* $p < .01$.

RESULTS

Patient's characteristics and test performance are shown in table 1. Four patients declined to participate, and 1 patient had to be excluded because of an inability to obtain a satisfactory $PETCO_2$ trace. All other participants completed the study uneventfully. There was no difference between the groups in the time since the incident fall and the study taking place. There were no differences between the groups in pain scores or in MVC (table 1). FES and HAD scores were significantly higher in the fear of falling group ($p < .01$). The anxiety component of the HAD scale was also significantly higher in the fear of falling group ($p < .01$). Avoidance of activity because of fear was reported by 14 of 20 of the fear of falling patients but by none of the control group (χ^2 test, $p < .01$). There was no significant relation between the time from fall and FES or HAD scores. No correlation was seen between FES scores and pain scores or MVC.

Sustained Isometric Muscle Contraction

$PETCO_2$ and RR at baseline and nadir values during SIMC are shown in figures 1A, 1B. Four of the fear of falling patients found it difficult to maintain their target force compared with 2 in the control group. Nadir values occurred at the end or near the end of the sustained contraction in all patients. Both groups had falls in $PETCO_2$ during sustained contraction ($p < .01$). Although mean RR rose in both groups, in neither group did it achieve statistical significance. Within each group, 2 patterns of response emerged: some patients had marked increases in RR and decreases in $PETCO_2$ ($n = 5$, controls; $n = 10$, fear of falling) whereas the rest showed smaller changes in RR and in $PETCO_2$. Baseline and nadir values for $PETCO_2$ were significantly lower in the fear of falling group compared with controls ($p < .01$). RR was lower at baseline and nadir in the control group than in the fear of falling group, but this did not reach statistical significance.

5-Meter Walk

The results presented are the mean value for 2 walks. $PETCO_2$ and RR responses for the fear of falling and control groups are

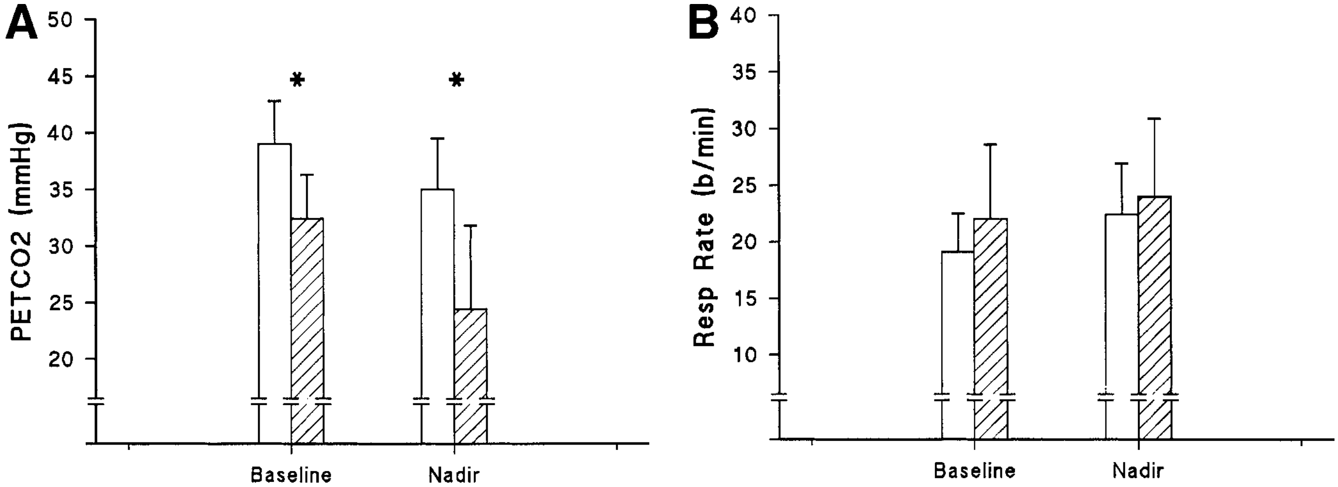

Fig 1. (A) PETCO_2 at baseline and nadir during SIMC in patients with fear of falling (▨) and controls (□). (B) RR at baseline and nadir in patients with fear of falling (shaded) and controls (unshaded). *$p < .01$.

shown in figures 2A, 2B. In each group, standing was accompanied by increased RR and decreased PETCO_2. Nadir PETCO_2 was accompanied by increased RR in each group. At all measurement points of the 5-meter walk, the PETCO_2 level was statistically significantly lower in the fear of falling group. RR was higher in the fear of falling group at all points compared with controls, but was statistically significant only at the nadir PETCO_2 and at the end of the walk.

Relationship Between FES and HAD Scores and RR and PETCO_2 During SIMC and 5-Meter Walk

A significant correlation was seen between the FES and HAD scores only in the fear of falling group ($r = .65$, $p < .01$). In the fear of falling group only, the HAD score correlated significantly with baseline RR and nadir RR ($r = 0.54$, $r = 0.55$, respectively, $p < .01$), but not PETCO_2, during SIMC. The correlation between FES scores did not reach statistical significance ($r = 0.45$, $p = .051$).

During the 5-meter walk, the HAD score correlated with baseline RR ($r = 0.51$, $p = .02$). The correlation between FES score and baseline RR did not reach statistical significance ($r = 0.45$, $p = .052$). Negative correlations were seen between PETCO_2 and the HAD score during the walk, but only achieved statistical significance at the end of the walk ($r = -.46$, $p = .05$). There were no correlations between MVC and PETCO_2 levels in either group during the 5-meter walk. No correlation was seen between pain scores (VAS) and PETCO_2 or RR. No correlations were seen between the percentage change from baseline to nadir of RR and PETCO_2 during isometric contraction and the 5-meter walk. Baseline PETCO_2 during SIMC and 5-meter walk correlated ($r = .65$, $p = .0018$) as did nadir values in each procedure ($r = 0.5$, $p = .025$). Baseline RR during SIMC and 5-meter walk correlated ($r = .74$, $p = .0002$) as did nadir RR in each procedure ($r = .53$, $p = .016$)

DISCUSSION

In this study, and as reported previously,[10-12] we have shown that SIMC leads to falls in PETCO_2. In patients with fear of falling, this was more marked than in controls because baseline PETCO_2 was lower. We also found that in patients with fear of

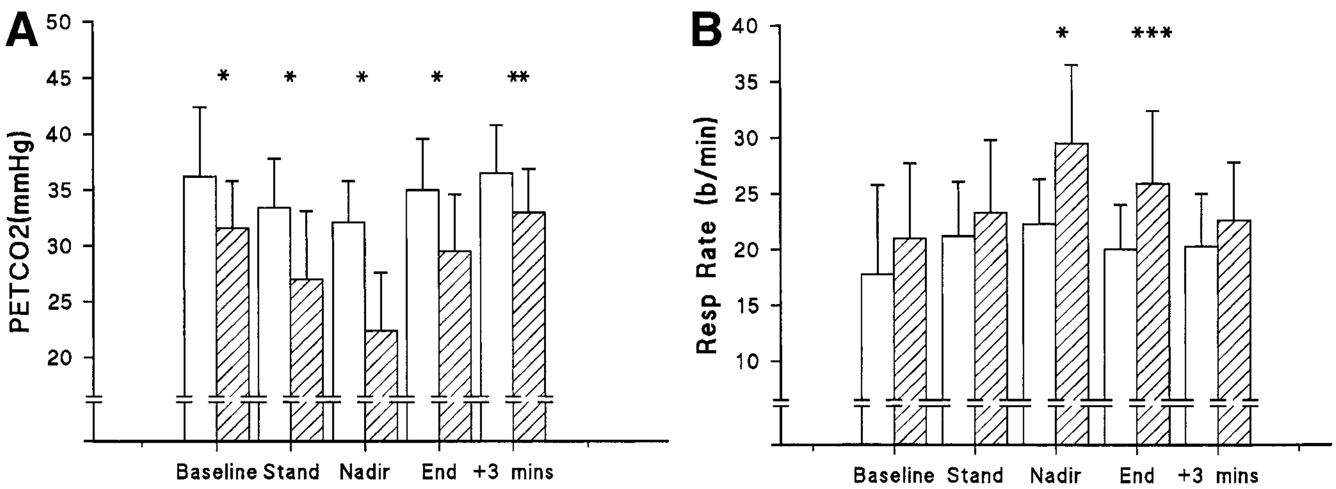

Fig 2. (A) PETCO_2 throughout 5-meter walk in patients with fear of falling (▨) and controls (□). (B) RR throughout 5-meter walk in patients with fear of falling (shaded) and controls (unshaded). *$p < .01$. **$p < .02$. ***$p < .05$.

falling, P_{ETCO_2} was lower at rest, at nadir, and at 3 minutes after a 5-meter walk. RR rate was also significantly higher at the nadir and at the end of the walk in the fear of falling group. We had expected that patients with fear of falling might be weaker and, therefore, more likely to have lower P_{ETCO_2} levels because of the need to use a greater proportion of their MVC in rising from a chair and walking, akin to SIMC. This was not the case because there was no difference in MVC between the groups.

We found a significant correlation between FES and HAD, which has also been reported previously.[4] In the fear of falling group, we observed a relation between RR at rest at the start of SIMC and the 5-meter walk and HAD scores, suggesting that anxiety may be a contributory factor. During the 5-meter walk, P_{ETCO_2} levels correlated negatively with HAD and FES scores, but the relationships only reached statistical significance at the end of the walk. Pain is known to be associated with hypocapnia, but we found no relationship with VAS pain scores, and no differences between our groups. Hypocapnia is also reported in severe or endogenous depression,[17] but none of our patients had this diagnosis. We measured P_{ETCO_2} at the nostril, a technique that has been reported to match measurements at the mouth and to provide a close approximation, in healthy patients, to Pa_{CO_2}.[16] We excluded patients with COPD, in whom P_{ETCO_2} is underestimated. Although our examiners were blinded to patient group and FES and HAD scores, patient behavior during the 5-meter walk may have indicated to which group individuals belonged.

Hypocapnia may be accompanied by various symptoms, through 2 main mechanisms. Reduction in blood flow to the brain, heart, and limbs produces dizziness and lightheadedness, cold extremities, and chest pain, respectively. Respiratory alkalosis causes neuronal irritability and may produce tetany muscle spasms and paresthesia. A role in syncope is well recognized,[18] and a diagnostic tilt test procedure including capnography has been proposed.[19] In healthy patients, voluntary hyperventilation increases postural sway,[20,21] possibly through deranged central and peripheral mechanisms. Increased sway is reported within 30 seconds of hyperventilation.[21] We did not ask our patients about symptoms of hyperventilation, but 14 had nadir P_{ETCO_2} levels at or below 25mm Hg, which is sufficient to induce symptoms[22] and possibly influence balance.[21]

CONCLUSION

We have shown that hypocapnia can occur during SIMC and during walking in elderly patients with fear of falling. Anxiety seems to be the main cause, but muscle weakness may contribute. Further studies are needed to examine the symptoms of hyperventilation in patients with fear of falling. Breathing and/or relaxation techniques and reconditioning may have a role in the treatment of patients with fear of falling in the rehabilitation setting.[23]

References

1. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons in the community. N Engl Med J 1988;319:1701-7.
2. Close J, Ellis M, Hooper R, Glucksman E, Jackson S, Swift C. Prevention of falls in the elderly trial (PROFET): a randomised controlled trial. Lancet 1999;353:93-7.
3. Tinetti ME, Speechley M. Prevention of falls among the elderly. N Engl J Med 1989;320:1055-9.
4. Tinetti ME, Richman D, Powell LE. Fall efficacy as a measure of fear of falling. J Gerontol 1990;45:239-43.
5. Maki BE, Holliday PJ, Topper AK. Fear of falling and postural performance in the elderly. J Gerontol 1991;46:M123-31.
6. JH Downton, K Andrews. Postural disturbance and psychological symptoms amongst elderly people living at home. Int J Geriatr Psych 1990;5:93-8.
7. Tinetti ME, Mendes deLeon CF, Doucette JT, Baker DI. Fear of falling and falls-related efficacy in relationship to functioning among community-living elders. J Gerontol 1994;49:M140-7.
8. Maki BE, Holliday PJ, Topper AK. Fear of falling and postural performance in the elderly. J Gerontol 1991;46:M123-31.
9. Maki BE. Gait changes in older adults: predictors of falls or indicators of fear? J Am Geriatr Soc 1997;45:313-20.
10. Imms FJ, Mehta D. Respiratory responses to sustained isometric muscle contractions in man: the effect of muscle mass. J Physiol (Lond) 1989;419:1-14.
11. Poole DC, Ward SA, Whipp BJ. Control of blood-gas and acid-base status during isometric exercise in humans. J Physiol (Lond) 1988;396:365-77.
12. Imms FJ, Russo F, Iyawe VI, Segal MB. Cerebral blood flow during and after sustained isometric skeletal muscle contractions in man. Clin Sci 1998;94:353-8.
13. Gardner WN, Bass C. Hyperventilation in clinical practice. Br J Hosp Med 1989;41:73-81.
14. Hodkinson HM. Evaluation of a mental test score for assessment of mental impairment in the elderly. Age Ageing 1972;1:233-8.
15. Zigmond AS, Snaith RP. The Hospital Anxiety and Depression Scale. Acta Psychiatr Scand 1983;67:361-70.
16. Gardner WN, Meah MS. Controlled study of respiratory responses during prolonged measurement in patients with chronic hyperventilation. Lancet 1986;ii:826-30.
17. Damas-Mora J, Souster L, Jenner FA. Diminished hypercapnic drive in endogenous or severe depression. J Psychosom Res 1982;26:237-45.
18. Perkin GD, Joseph J. Neurological manifestation of the hyperventilation syndrome. J Roy Soc Med 1986;79:448-50.
19. Naschitz JE, Gaitini L, Mazov I, Eridzhanyan L, Keren D, Sabo E, et al. The capnography-tilt test for the diagnosis of hyperventilation syncope. Q J Med 1997;90:139-45.
20. Sakellari V, Bronstein AM, Corna S, Hammon CA, Jones S, Wolsley CJ. The effect of hyperventilation on postural control mechanisms. Brain 1997;120:1659-73.
21. Sakellari V, Bronstein AM. Hyperventilation effect on postural sway. Arch Phys Med Rehabil 1997;78:730-6.
22. Rafferty GF, Saisch SGN, Gardner WN. Relation of hypocapnic symptoms to rate of fall of end-tidal PCO_2 in normal subjects. Resp Med 1992;86:335-40.
23. Timmons BH, Ley B, editors. Behavioral and psychological approaches to breathing disorders. New York: Plenum; 1994.

Suppliers

a. Portable pressure transducer, MIE, Medical Research Ltd, 6 Wortley Moor Rd, Leeds S12 4JF, UK.
b. Datex Engstrom Division, Instrumentation Corp, P.O. Box 900, FIN-00031, Finland.
c. Arcus Pro-Stat, 1994, Medical Computing, 83 Turnpike Rd, Aughton L39 3LD, UK.