Blood pressure changes on upright tilting predict falls in older people

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Abstract

Background: orthostatic hypotension may be an important risk factor for falls, though this has not yet been demonstrated in prospective studies. This may be because conventional methods of measuring blood pressure changes are too imprecise and not optimally timed.

Objectives: to determine whether changes in blood pressure induced by upright tilt are associated with falls in older people, and whether medication use and symptoms of dizziness are associated with blood pressure changes and falls.

Methods: seventy men and women aged 62–92 years participated. We measured blood pressure with a plethysmograph monitor continuously before and after upright tilt. We recorded medication use and symptoms of dizziness in response to the tilt. Subjects were then followed up for 12 months to determine the incidence of falls.

Results: subjects who fell in the follow-up period had significantly greater decreases in systolic blood pressure when tilted than those who did not fall. Furthermore, those who had unstable systolic blood pressure during the 3 minutes after tilting, in addition to large blood pressure drops, had a two-fold increased risk of falling compared with those with neither of these conditions. Symptoms of dizziness on tilting were uncommon and not associated with blood pressure or heart rate changes, medication use, or falls incidence. Antidepressant and antihypertensive medication use were associated with decreases in diastolic rather than systolic blood pressure, but were not associated with falls.

Conclusions: these findings indicate that both the decrease in blood pressure and the unstable nature of the blood pressure response following upright tilt are useful predictors of falls in older people.

Keywords: blood pressure, falls, upright tilt, orthostatic hypotension

Background

Orthostatic hypotension (OH) is a marked fall in blood pressure (BP) on standing or being tilted upright from a supine position. It may be asymptomatic or accompanied by symptoms of dizziness or light-headedness [1]. The prevalence reported for OH in older people varies considerably, ranging from 6–33% [2–10]. This large variation has been attributed to differences in the populations assessed, the technique of measuring BP, and how OH was defined [4, 11, 12].

OH has been considered an important risk factor for falls since 1960 when Sheldon reported that 4% of 500 falls in 202 older people were attributed to ‘abnormal blood pressure homeostasis’ [13]. Other studies have since reported that OH is prevalent in older people with frequent falls [4, 14]. However, OH has only been significantly associated with falls in a minority of large prospective population studies examining falls risk factors. Graafmans et al. reported that OH was more prevalent in 354 elderly people living in assisted accommodation [10], and Ooi et al. identified OH as a risk factor for recurrent falls in only a subset of nursing home residents who had previously fallen [15]. More commonly, prospective studies conducted in both the community [16–19] and in aged-care residential care [20] find no significant association. Similarly, a study of more than 9000 women did not find OH to be a risk factor for falls [5] or hip fracture [21].

The inconsistent association between OH and falls may arise through limitations in measuring BP changes in response to standing or an upright tilt. In particular, a single sphygmomanometer assessment up to 5 min after rising may be too imprecise to determine significant BP changes and miss immediate BP falls.
**Objective**

This is a prospective cohort study to determine whether falling in older people is associated with immediate or sustained BP changes in response to a head-up tilt, and whether medication use and subjective feelings of dizziness are associated with the BP changes.

**Methods**

**Subjects**

We recruited 14 men and 56 women ranging in age from 62–92 years aged 76.5 ± 5.9 years (mean ± SD) the subjects were residents of two retirement villages in Sydney, Australia. They had been ‘control’ subjects in a larger falls prevention study [22]. We excluded subjects if they had Short Portable Mini-Mental Status Examination scores <21 [23] because people with cognitive impairments report falls less reliably [24]. Baseline characteristics of the sample are shown in Table 1.

**Blood pressure and heart rate assessment**

We assessed subjects between 10 am and 4 pm. A centrally pivoted tilt table with footboard support was used to change posture. After 5 minutes of supine rest, the subject was manually tilted head-up by 60° for 10 seconds.

We monitored BP continuously using a pulse plethysmograph (Ohmega-2300 Finapres) and recorded it on a polygraph (Grass-Telefactor, USA). The cuff was placed around the left middle finger, which was kept in a fixed position at heart level with a splint and sling. Changes in BP measured with this device correspond with sphygmomanometer and direct intra-arterial recordings [25–28]. Before tilting, brachial arterial BP was measured with a sphygmanometer.

We calculated heart rate (HR) and BP for 3 points: before the tilt, immediately after the tilt (10 seconds), and 3 minutes after the tilt. We calculated HR from the mean of 10 pulse intervals, and we calculated systolic and diastolic pressures as the mean of 10 pulse waves (approximately two respiratory cycles). Subjects were asked if they felt dizzy or light headed during and after the tilt.

**Medication use and dizziness**

At the beginning of the study, we recorded medications used by subjects from their container labels. Subjects completed a questionnaire that asked whether they experienced dizziness or light-headedness when they stood up.

**Falls**

Falls were recorded using monthly questionnaires and follow-up calls if required [19, 20]. A fall was defined as an event in which the subject unintentionally came to rest on the ground or at a lower level [19].

**Statistical analysis**

We compared age and baseline HR and BP for sub-groups of the sample (e.g. fallers vs non-fallers, medication users vs non-users) using grouped t-tests and Mann–Whitney U tests (when group sizes were small). HR and BP changes evoked by the tilt were compared using repeated-measure ANOVA assessing group (faller status) by time (BP measurements pre- and post-tilt) interactions. We classified subjects as having OH or not, based on a 20 mmHg or more drop in systolic BP and the relative risk statistic for falling calculated. Data were analysed using SPSS [29].

**Results**

**Orthostatic hypotension and falls**

Thirty-six of 70 subjects (51%) reported one or more falls in the follow-up year. Of the fallers, 17 fell only once (24%) and 19 (27%) fell two or more times. The ages of the faller (76.3 ± 6.4; mean ± SD) and non-faller (76.7 ± 5.4) groups were equivalent. For the fallers and non-fallers there were no significant differences between the initial resting systolic BP (149.7 ± 3.4 and 150.2 ± 3.2 mmHg respectively) and diastolic BP (80.2 ± 1.6 and 83.7 ± 1.5 mmHg). The resting HR of the faller group was 6.2% less than that of the non-fallers (69.7 ± 1.9 and 74.3 ± 1.7 bpm), though this difference only approached statistical significance (t68 = 1.83, P=0.07).
Orthostatic hypotension and falls

Figure 1 shows HR and BP changes on tilting for fallers and non-fallers. There was no significant difference between the HR increases of fallers and non-fallers (main effect $F_{1,136}=0.68$, $P=0.41$). Despite this, there were significant differences between the changes in systolic BP (main effect $F_{1,136}=5.84$, $P<0.05$). Immediately after the tilt, mean systolic BP of the non-fallers was equivalent to pre-tilt levels ($−0.5±17.9$ mmHg), whereas for the fallers it was below pre-tilt levels ($−6.3±21.2$ mmHg). During the next 3 minutes, the mean systolic BP of the non-fallers had risen to above pre-tilt levels ($+5.7±17.6$ mmHg) but that of the fallers had not yet risen to pre-tilt levels ($−3.6±16.8$ mmHg). At 3 minutes, 8 of the 36 fallers (22%) had BP decreases $≥20$ mmHg, compared with only 2 of the 34 non-fallers (6%), representing a 70% increased risk of falling associated with this decrease in BP ($RR=1.71$, 95% CI =1.14–2.59).

Of the 36 fallers, 3 reported ‘fainting’ or ‘black-outs’ as the cause of one or more of their falls. These subjects had greater immediate systolic BP decreases than those who did not report that they fell through fainting ($−26.1±8.2$, $−25.2±4.4$ mmHg, Mann–Whitney $U$ test $=29.0$, $z=−2.07$, $P<0.05$).

BP responses after tilt showed greater instability for fallers than for non-fallers (Figure 2). There was a weak association between the immediate increase in systolic BP and the increase at 3 minutes for the fallers, but a strong association among the non-fallers ($r^2=0.21$ and 0.61 respectively, $P<0.05$). Thus, the non-fallers showed a relatively fast BP change in response to the tilt, with stable levels thereafter. In contrast, the fallers tended to have a greater immediate decrease in BP and an inconsistent response over the subsequent 3 minutes. In fact, 19 of the 36 fallers (53%) had absolute differences in BP of more than 10 mmHg between the immediate and 3-minute assessments, compared with only 11 of the 34 non-fallers (32%). This difference approached statistical significance ($RR=1.49$, 95% CI =0.95–2.34).

Compared to those with neither a large decrease in BP at 3 minutes nor unstable BP post tilt, those who had either a systolic BP drop $≥20$ mmHg or a difference in systolic BP $≥10$ mmHg between the immediate and 3-minute assessments had an increased risk of falling of 2.15, 95% CI =1.16–3.98 ($\chi^2$ for linear trend $=6.01$, df=1, $P<0.05$).

Orthostatic hypotension and symptoms of dizziness

Seven subjects (10%) reported symptoms of dizziness in response to the tilt and 24 subjects (34%) reported these symptoms when they occasionally or mostly stood up. There were no significant differences in HR and BP changes between those who felt dizzy after tilting and those who did not. Those who reported feeling dizzy when they usually stood up had greater increases in HR after tilting than those without symptoms, both immediately ($8.8±8.3$, $4.7±6.1$ bpm, $t_{68}=2.34$, $P<0.05$) and at 3 minutes ($11.8±6.5$, $7.7±7.7$ bpm, $t_{68}=2.21$, $P<0.05$). There were no significant associations between the two dizziness measures and falls: dizzy on tilt ($RR=0.82$, 95% CI =0.34–1.99), dizzy when standing ($RR=1.22$, 95% CI =0.78–1.92).

Orthostatic hypotension and medications

We found significant associations between OH and medication use only for antihypertensive and antidepressant categories. Thirty subjects (43%) were taking one or more antihypertensive medications (ACE-inhibitors 19, beta-blockers 9, diuretics 13) and 8 (11%) antidepressants (tricyclics 6, MAO inhibitors 2). Those taking antihypertensives had greater immediate decreases in diastolic BP than non-users, ($−0.9±7.6$ and $5.3±10.5$ mmHg respectively, $t_{68}=2.72$, $P<0.01$) and smaller diastolic BP increases at 3 minutes.
(4.0 ± 8.1 and 9.9 ± 8.6 mmHg respectively, t_{68} = 2.90, P < 0.01). Those taking antidepressants had greater immediate decreases in diastolic BP than non-users (−5.8 ± 7.1 and 3.8 ± 9.6 mmHg respectively, t_{68} = 2.70, P < 0.01). There were no associations between anti-hypertensive (or any sub-class) or antidepressant use and falls (RR = 0.95, 95% CI = 0.60–1.51 and RR = 0.97, 95% CI = 0.46–2.02 respectively).

Discussion

The prevalence of OH in this independent-living population was 14%, a prevalence rate in the mid range of that reported in other population studies of older people, i.e. 6–33% [2, 5, 6, 8, 16, 17]. A decrease in systolic BP at 3 minutes after upright tilting was significantly associated with falls during the following year. This was so when the OH was quantified and when classified by the OH criterion of a 20 mmHg or more drop in systolic BP. Those who had unstable systolic BP, indicated by a difference in systolic BP ≥ 10 mmHg between the immediate and 3-minute assessments after tilting, in addition to large blood pressure drops, had a more than double risk of falling compared with those with neither condition.

The failure of the faller group to maintain or increase systolic BP on tilting, together with the instability in BP during the 3 minutes after tilting, indicates that some of these subjects have problems with short-term cardiovascular homeostasis. As assessed by its chronotropic effect, the baroreceptor reflex response to tilting was equally intense and brisk among the non-faller and faller groups. The reflex normally acts to maintain carotid BP, and therefore raise BP at heart level, and this was observed in the non-faller group. However, in the faller group, systolic BP fell despite the same increase in HR, suggesting that in these subjects, tilting caused a large drop in stroke volume and cardiac output. However, the mean drop in systolic BP was not large—about 10 mmHg less than in the non-faller group. It is likely that these responses are a slight underestimate because, for safety reasons, subjects were only tilted 60° rather than 90° to full upright. Also, positioning the finger on the chest measured BP slightly above heart level with subjects supine, but slightly below heart level when tilted. Nevertheless, a reduction of this amount should have little physiological effect and is unlikely to lead to falls. In agreement with this, very few subjects reported symptoms of dizziness on tilting. It seems more likely that we have measured the BP responses on a typical day, but these unstable responses could indicate occasional much larger BP changes that contribute to falls.

In contrast with the study by Ensrud et al. [5], we did not find that postural dizziness was significantly associated with falls. Symptoms of dizziness on tilting were uncommon and not associated with HR changes, BP changes, or medication use. However, those who reported dizziness when they mostly or occasionally stood up had greater HR increases in response to the tilt, suggesting that symptoms of dizziness could be associated with an intense baroreceptor reflex.
The use of antihypertensive and antidepressant medications may lead to falls by the mechanism of OH [3, 10, 16]. In this population, these medications were not associated with falls. Both medication groups were significantly associated with larger decreases in diastolic BP, particularly immediately after tilting. In contrast, falls were associated with larger decreases in systolic BP, and no diastolic BP, and these effects were greatest 3 minutes after tilting rather than immediately. This suggests that hypotension-induced falls may have a specific physiological link with changes in systolic BP.

The association between OH and subsequent falls has not been seen in most previous population studies [5, 16–20], and this lack of evidence-based findings has raised doubts about OH as a falls-risk predictor [3]. Far from being stable, BP varies substantially in response to both natural and induced factors, including the time of day, time after meals and medications [1, 30]. It is also apparent that the BP response after rising is unstable, particularly among the fallers. These inherent difficulties in assessing OH may contribute to this unclear picture. Despite the limitation of taking only one assessment during the day, it appears that the continuous and accurate BP measurement used in this study allowed the cardiovascular parameters associated with falls to be identified. It is possible that passive tilting, rather than active standing, more accurately identifies older people with impaired haemodynamic responses. A tilt table standardises the time taken to attain upright posture and removes the variable muscular activity used to stand [28, 31–33]. It also allows inclusion of subjects with the worst balance who would be necessarily excluded if they were required to stand unaided.

The causes of falls are multifactorial, with few due to a single risk factor [17, 18]. Most studies identify sensory and neuromuscular impairments as the most important risk factors for falls. Accordingly, the most frequently reported causes of falls are trips, slips and loss of balance [34]. This was true in the larger population from which this sample was drawn [22], and OH was likely to be the major predisposing factor for only a minority of falls. These findings indicate that an accurate measure of BP change identifies the 5–10% of older people at risk of falling due to impaired haemodynamic responses. Thus, careful assessments of systolic BP following an upright tilt, including measurements both immediately and 3 minutes after tilting, may complement assessments of sensation, strength and balance currently used to identify older people at risk of falls.

It is acknowledged that the study has certain limitations. First, as the study was conducted within a retirement village setting, the findings may relate best to only this sub-group of the older population. Secondly, the sample size is relatively small, and given that multiple comparisons were made it is possible that some of the associations evident may be subject to type I errors. Therefore, the findings require validating by other studies.

Further studies could compare standard BP assessments using brachial sphygmomanometry on two or more occasions after both tilting and standing to determine whether these assessments reliably measure BP instability and identify older people at risk of falling due to impaired haemodynamic responses.

**Key points**
- Older people with a decrease in systolic blood pressure ≥20 mmHg after upright tilting are at significantly increased risk of falls.
- Older people with a decrease in systolic blood pressure ≥20 mmHg together with unstable systolic blood pressure during the 3 minutes after tilting have more than double the risk of falling compared with those with neither of these conditions.
- Symptoms of dizziness and antihypertensive and antidepressant drug use were not significantly associated with systolic blood pressure drops or falls.

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**References**

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