Effect of measuring ambulatory blood pressure on sleep and on blood pressure during sleep

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Abstract

***Objective*—To assess whether recording of ambulatory blood pressure at night causes arousal from sleep and a change in the continuous blood pressure recorded simultaneously.**

***Design*—Repeated measurement of blood pressure with two ambulatory blood pressure machines (Oxford Medical ABP and A&D TM2420) during continuous measurement of beat to beat blood pressure and continuous electroencephalography.**

***Setting*—Sleep reseach laboratory.**

***Subjects*—Six normal subjects.**

***Main outcome measures*—The duration of electroencephalographic arousal and the beat to beat changes in blood pressure produced by the measurement of ambulatory blood pressure; the size of any changes that this arousal and change in blood pressure produced in the blood pressure recorded by the ambulatory machine.**

***Results*—Both ambulatory blood pressure machines caused arousal from sleep: the mean duration of arousal was 16 seconds (95% range 0-202) with the ABP and 8 seconds (0-73) with the TM2420. Both also caused a rise in beat to beat blood pressure. During non-rapid eye movement sleep, this rise led to the ABP machine overestimating the true systolic blood pressure during sleep by a mean of 10 (SD 14·8) mm Hg and the TM2420 by a mean of 6·3 (8·2) mm Hg. On average, diastolic pressure was not changed, but measurements in individual subjects changed by up to 23 mm Hg. These changes varied in size among subjects and stages of sleep and were seen after measurements that did not cause any electroencephalographic arousal.**

***Conclusions*—Ambulatory blood pressure machines cause appreciable arousal from sleep and therefore alter the blood pressure that they are trying to record. This effect should be taken into account when recordings of blood pressure at night are interpreted in clinical work and epidemiological research.**

Introduction

Twenty four hour recordings of ambulatory blood pressure are widely used in diagnosing and treating hypertension as well as in epidemiological studies. These profiles are better at predicting cardiovascular mortality and morbidity than isolated measurements done in clinics[1] and avoid the misleading rise in blood pressure that can occur when measurements are made by medical staff.[2] O'Brien *et al* suggested that the absence of the normal reduction in blood pressure at night during ambulatory recordings may be an independent predictor of hypertensive end organ damage.[3] However, transient auditory and tactile stimuli delivered during sleep and lasting only a few seconds cause a transient rise in blood pressure even if cortical electroencephalographic arousal does not follow.[4] Previous work has suggested that this rise may cause appreciable disturbances in blood pressure during ambulatory measurement.[4] This study aimed to establish if this effect is likely to be important in recordings of ambulatory blood pressure at night.

Subjects and methods

We studied six normal adults (two women) aged 19 to 21 with no history of cardiovascular disease or disease related to sleep. The study was approved by Central Oxford Research Ethics Committee.

RECORDING AMBULATORY BLOOD PRESSURE

We studied each subject twice, using a different ambulatory blood pressure machine on each occasion. The two machines used were the ABP (Oxford Medical, Abingdon, United Kingdom) and the TM2420 (A&D Limited, Tokyo, Japan). Three subjects were randomised to one machine first and three to the other, and the two recordings for each subject were made at least two weeks apart. Recordings were started at 0900, and measurement cycles (approximately 60 seconds) were initiated every 30 minutes throughout the following 24 hours. During sleep the pressure in the arm cuff of the machine was monitored with a calibrated pressure line connected to the inflation tubing and was continuously stored with the data on beat to beat blood pressures (see below).

SLEEP STAGES AND AROUSAL

The subjects slept in a sleep laboratory and were continuously monitored with an infrared audiovisual recording system. Overnight an electroencephalogram (C_2/A_3), eye movements (two channels), and a chin electromyogram were recorded; the subjects' sleep was staged from these signals according to standard criteria.[5]

We noted the duration of each arousal from sleep that was due to inflation of the cuff measuring the ambulatory blood pressure. During non-rapid eye movement sleep the duration was taken as the duration of increased high frequency activity in the electroencephalogram, but during rapid eye movement sleep it was taken as the duration of increased activity in the electromyogram as high frequency activity is spontaneously present in an electroencephalogram in this stage of sleep. We staged sleep and calculated the duration of arousals blind, before analysing the blood pressure recordings.

BEAT TO BEAT BLOOD PRESSURE DURING SLEEP

Arterial beat to beat systolic and diastolic blood pressures were recorded from the third finger of the hand contralateral to that linked to the ambulatory blood pressure machine with an infrared plethysmographic volume clamp (Finapres, Ohmeda, Colorado, United States).[6] The blood pressures were synchronised with the stages of sleep, and the pressure from the ambulatory cuff was continuously stored with the beat to beat blood pressures.

Analysis of the changes in the beat to beat blood pressure during ambulatory recording was limited to those measurement cycles in which the hand from which the beat to beat blood pressure was being recorded did not move for one minute after the cuff

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had started to inflate. This was confirmed from the audiovisual recording and the absence of movement artefacts in the record of blood pressure.

The average systolic and diastolic pressures over the last 10 seconds before inflation of the cuff were used as the baseline with which subsequent changes were compared. The systolic and diastolic changes from the baseline were calculated for each of the next six periods of 10 seconds, and the peak blood pressure during these 60 seconds was noted.

The effects of the rise in blood pressure during ambulatory measurement on the recorded systolic and diastolic pressures were expressed as the change in beat to beat blood pressure from the baseline to the point at which the ambulatory machine identified the systolic and diastolic pressures. The time at which the ambulatory machine identified these pressures was taken to be when the pressure during the deflation of the arm cuff equalled the subsequently reported systolic and diastolic pressures.

STATISTICAL ANALYSIS

The duration of electroencephalographic arousal that was due to the measurement of ambulatory blood pressure was expressed for each machine as a median, with 95% and 100% ranges. For each subject the average disturbance of blood pressure over the first minute after the cuff had inflated was calculated. The average effect (and the standard deviation) of these changes on the systolic and diastolic pressures recorded with each machine in each subject were calculated. The significance of these changes was assessed with the paired t test.

Results

In all, 104 error free measurement cycles (48 with the ABP and 56 with the TM2420) were completed during sleep (confirmed by the electroencephalogram) without movement of the hand attached to the beat to beat blood pressure monitor. Of these, 88 were obtained during non-rapid eye movement sleep and 16 during rapid eye movement sleep; 37 of the measurement cycles during non-rapid eye movement sleep occurred during stage 3 or 4 sleep. Most of the measurement cycles not analysed were rejected because the arousal induced during inflation of the cuff was so great that the hand attached to the volume clamp moved.

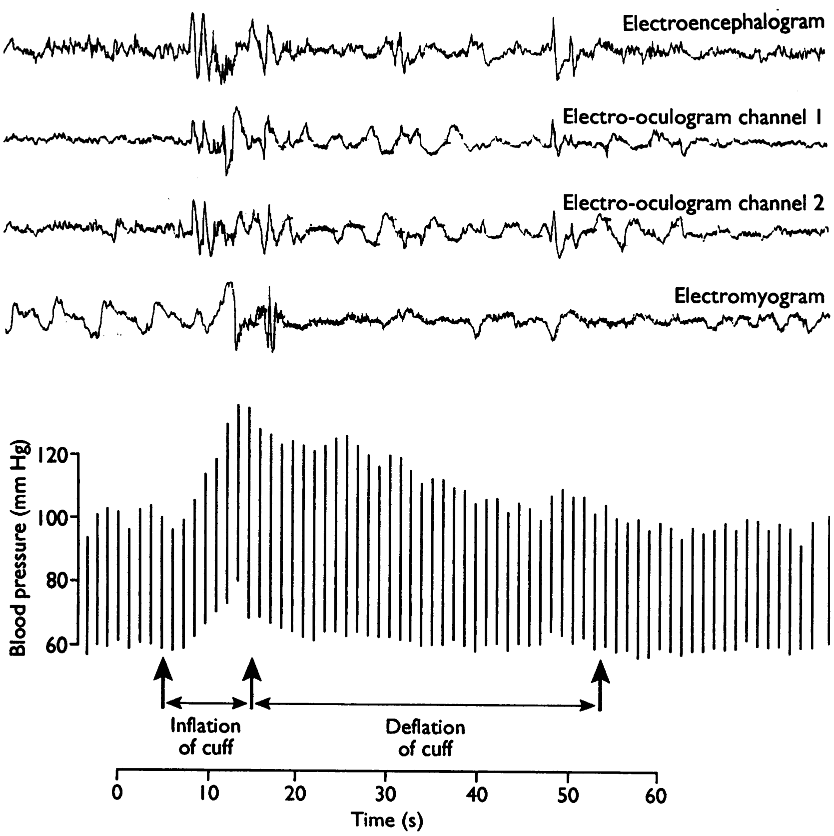

FIG 1—*Example of beat to beat blood pressure during one measurement cycle of ambulatory blood pressure recorded from contralateral arm. Measurement occurred during stage 2 sleep. Arousal during cuff inflation is shown in electroencephalogram and electromyogram*

SLEEP DISTURBANCE

Both ambulatory blood pressure machines caused arousals from sleep: the median duration of arousal with the ABP was 16 seconds (95% range 0-202, 100% range 0-517) and with the TM2420 eight seconds (95% range 0-73, 100% range 0-107). In total, 40 inflations of the cuff (16 with the ABP and 24 with the TM2420) during non-rapid eye movement sleep did not cause electroencephalographic arousal. The average duration of arousal from non-rapid eye movement sleep was shorter when a measurement cycle occurred during deep sleep (stage 1 or 2: median duration 22 seconds (95% range 0-100, 100% range 0-517); stage 3 or 4: median duration 0 seconds (95% range 0-31, 100% range 0-131)).

BLOOD PRESSURE DISTURBANCE

Figure 1 shows an example of the changes in beat to beat blood pressure in response to the measurement of the ambulatory blood pressure recorded from the contralateral arm during stage 2 sleep. Figure 2 shows the average pattern of changes in each subject during non-rapid eye movement sleep; the changes varied appreciably among subjects and were smaller with the TM2420. During the 60 seconds after the cuff had begun to inflate the average peak change in systolic and diastolic pressures was 27 (SD 14·7) mm Hg and 16 (8·9) mm Hg respectively with the ABP and 22 (10·4) mm Hg and 13 (8·1) mm Hg respectively with the TM2420.

In all six subjects some measurement cycles did not cause any electroencephalographic arousal but even these cycles caused a rise in blood pressure (average peak rise in systolic pressure 18 (10·7) mm Hg; average peak rise in diastolic pressure 9 (7·4) mm Hg). During rapid eye movement sleep the measurement cycles also raised blood pressure (average peak rise in systolic pressure 24 (16·8) mm Hg) average peak rise in diastolic pressure 14 (8·4) mm Hg).

EFFECT OF RISE IN BLOOD PRESSURE DURING AMBULATORY CUFF MEASUREMENTS

The table shows the changes in blood pressure from the baseline to the point at which the ambulatory machine identified the systolic and diastolic pressures for each subject; in five of the six subjects the rise in systolic blood pressure was significant with one or both machines. On average, diastolic blood pressure was not changed by either machine, though changes of up to 23 mm Hg occurred during some cycles.

Discussion

This study shows that ambulatory blood pressure machines cause a rise in simultaneously recorded beat to beat systolic and diastolic blood pressures and that this rise is often associated with electroencephalographic arousal from sleep. Such a rise leads to an overestimate of the true systolic pressure during sleep, which varies among subjects and stages of sleep. In our study diastolic blood pressure on average remained unchanged. Even measurement cycles that did not cause electroencephalographic arousal caused a rise in blood pressure.

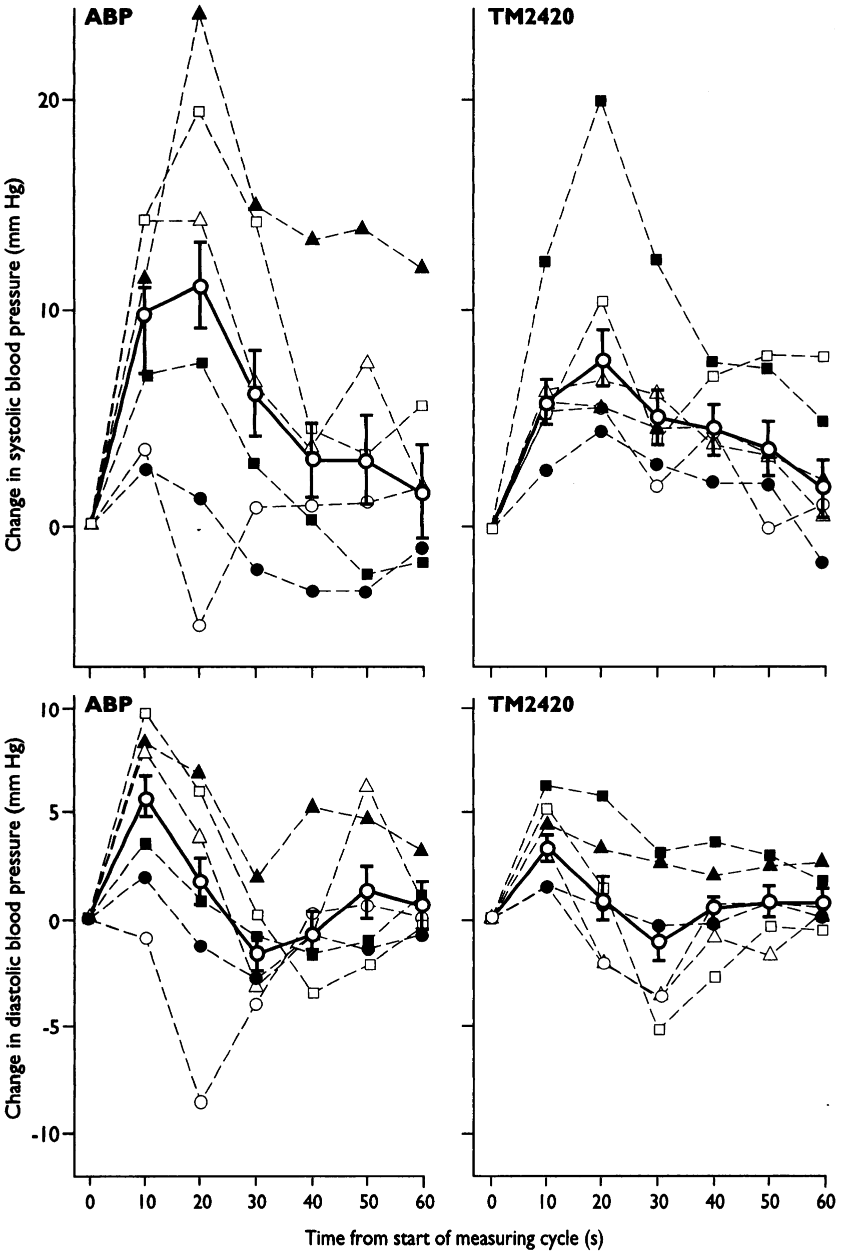

FIG 2—*Changes in beat to beat systolic and diastolic blood pressures during 60 seconds after onset of cuff inflation during non-rapid eye movement sleep. Dotted lines represent average patterns seen over one night in each subject; solid lines represent mean (and SEM) of all measurement cycles recorded*

PLETHYSMOGRAPHIC VOLUME CLAMP

Beat to beat blood pressure was recorded with the beat to beat blood pressure monitor from the arm contralateral to that linked to the ambulatory machine. This recording method depends on a pneumatic servo-controlled cuff, which is inflated to keep the infrared absorption in the finger constant by the correction of a photoplethysmogram. As changes in infrared absorption in the finger are due to variations in blood volume in the finger[6] the changes in cuff pressure needed to keep the photoplethysmogram constant reflect changes in intravascular pressure.[6,7] This is an accurate method of monitoring changes in blood pressure and can track the changes that occur during the Valsalva manoeuvre, the Müller manoeuvre, atrial fibrillation,[8] and obstructive sleep apnoea[9] (physiological stresses that cause faster changes in blood pressure than occurred in this study). As digital arterial pressure differs from brachial arterial pressure because of the hydrostatic effects of the position of the hand[8,9] and the normal change in blood pressure along the vascular tree,[10] the plethysmographic volume clamp is best used as an index of change in blood pressure rather than of absolute pressure.[8] For this reason, only changes in blood pressure are reported in this study.

EFFECTS OF AROUSAL ON BLOOD PRESSURE

To avoid artefacts arising from movements of the hand, data on blood pressure were gathered only from measurement cycles in which video monitoring showed no hand movements and in which no movement artefacts were seen in the trace of the blood pressure. Movement is a marker of substantial arousal, and greater arousals tend to cause larger rises in blood pressure.[4] The results of this study are therefore probably an underestimate of the true effects of the two ambulatory machines on blood pressure during sleep.

The changes in blood pressure due to the ambulatory recorders are a manifestation of the general autonomic activation that accompanies an arousing event during sleep (the orienting reflex[4,11]). This reflex is a stereotyped feature of arousal that is not suppressed by repetition during sleep,[11-13] and its haemodynamic effects have been confirmed in several age groups, including young healthy adults[4,11] and obese middle aged men.[14] A rise in blood pressure without an electroencephalographic arousal is also consistent with previous studies that have induced autonomic changes with stimuli that are too small to affect the electroencephalogram.[4,11] Although the general characteristics of the orienting reflex are well described, its exact effects during recordings of ambulatory blood pressure have not been reported before. As this study examined only young healthy subjects the exact characteristics of this reflex in older subjects, in whom ambulatory blood pressure is usually recorded, need to be examined.

Our results complicate in several ways the interpretation of ambulatory blood pressure at night as an independent predictor of vascular morbidity and mortality. Stroke,[3] silent cerebrovascular disease,[15] and left ventricular hypertrophy[16] have been reported as more common in patients with a small or no reduction in ambulatory blood pressure at night. Such a reduction is usually ascribed to an absence of a normal reduction in blood pressure during sleep, resulting in a higher 24 hour blood pressure load.[16] Our study suggests another explanation: subjects with an apparently small reduction may be those with a particularly vigorous response to arousing stimuli. This is particularly likely if the systolic blood pressure is the end point of study. The variability of the changes in blood pressure depending on the stage of sleep and the brand of measurement machine is also important, particularly in the comparison of epidemiological studies.

OTHER STUDIES

Few studies have addressed the question of whether

Changes in blood pressure from baseline (during undisturbed sleep) to point at which two ambulatory blood pressure machines identified systolic and diastolic pressures in six normal adults aged 19-21

Subject No	Machine	No of measurement cycles with no movement of hand	Mean (SD) change in pressure (mm Hg)	
			Systolic	Diastolic
1	ABP	9	18·1 (13·2)**	5·7 (9·4)
	TM2420	10	6·6 (9·8)*	0·0 (5·3)
2	ABP	6	−4·0 (12·8)	0·8 (5·3)
	TM2420	7	1·2 (7·3)	−0·9 (3·6)
3	ABP	5	−0·2 (2·8)	−0·4 (3·2)
	TM2420	10	4·5 (4·6)*	0·3 (2·9)
4	ABP	5	24·5 (15·6)*	1·3 (5·0)
	TM2420	9	8·0 (9·4)*	2·6 (7·0)
5	ABP	9	15·8 (12·8)**	−3·6 (3·7)
	TM2420	6	9·0 (8·0)*	2·0 (7·0)
6	ABP	6	2·7 (7·4)	−0·5 (4·9)
	TM2420	6	9·6 (8·6)*	1·8 (6·6)

*P<0·05; **P<0·01 (paired *t* test).

Clinical implications

- Ambulatory blood pressure machines are widely used in the management of hypertension
- Blood pressure at night during ambulatory recordings is assumed to represent blood pressure during sleep, but the noise and the pressure on the arm of a recording cycle may disturb sleep
- This study shows that ambulatory blood pressure machines cause a variable rise in blood pressure and electroencephalographic arousal from sleep during measurements
- The changes in blood pressure caused by this arousal lead to an overestimation of true systolic pressure during sleep and a variable change in diastolic pressure
- The blood pressure recorded by ambulatory machines at night may underestimate to variable degrees the reduction in the blood pressure during sleep

ambulatory machines change blood pressure during sleep. Parati *et al* found that the average overnight reduction in intra-arterial blood pressure during sleep was preserved during simultaneous recordings with an ambulatory machine but did not report the detailed changes during the measurement cycles.[17] Schwan and Erikson examined the effect of measuring blood pressure during sleep and argued that ambulatory machines did not change the pressure because the reported blood pressures were similar regardless of whether three seconds of electroencephalographic arousal occurred during the measurement cycles.[18] Unfortunately, both the measurement cycles with arousal and those without (which were used as controls) would have been disturbed to a similar degree. Electroencephalographic arousals far shorter than three seconds are accompanied by substantial rises in blood pressure.[4] Indeed, both this study and that of Davies *et al*[4] show that significant rises in blood pressure occur without any electroencephalographic change at all.[4]

The changes in beat to beat diastolic pressure during recordings with the ambulatory machines were smaller than the changes in beat to beat systolic pressure for two reasons. Firstly, the size of the changes in ambulatory diastolic blood pressure were smaller than the changes in ambulatory systolic pressure (fig 2) and, secondly, diastolic blood pressure is measured after a longer delay, so that beat to beat blood pressure has had longer to return towards normal. This second factor is important for the design of future ambulatory machines. Shortening the delay between the start of inflation of the cuff and the measurement of the blood pressure (to make the procedure less intrusive) reduces the time for the effects of arousal to resolve and thus may increase the size of the change in the final blood pressure recording. Even though we found that the average change in the diastolic measurement was not significant, we found considerable variability among the subjects studied, and during one measurement cycle diastolic pressure was overestimated by 23 mm Hg.

In conclusion, this study examined the effects of two ambulatory blood pressure machines on sleep and on blood pressure during sleep. Both machines disturbed sleep and caused a rise in beat to beat blood pressure during the ambulatory measurement cycle. The more modern, and quieter, machine (TM2420) was the less disruptive of the two, but both overestimated true systolic blood pressure during sleep in some subjects. On average, diastolic blood pressure was accurately measured, although individual results were substantially disturbed. These results are important for interpreting recordings of ambulatory blood pressure at night and how they relate to risk of vascular disease.

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1 Perloff D, Sokolow M, Cowan R. The prognostic value of ambulatory blood pressures. *JAMA* 1983;249:2792-8.
2 Mancia G, Bertininieri G, Grassi G, Parati G, Pomidossi G, Ferrari A, *et al.* Effects of blood-pressure measurement by the doctor on patients' blood pressure and heart rate. *Lancet* 1983;ii:695-7.
3 O'Brien E, Sheridan J, O'Malley K. Dippers and non-dippers. *Lancet* 1988;ii:397.
4 Davies RJO, Belt PJ, Robert SJ, Ali NJ, Stradling JR. Arterial blood pressure responses to graded transient arousal from sleep in normal humans. *J Appl Physiol* 1993;74:1123-30.
5 Rechtschaffen A, Kales A. *A manual of standardised terminology, techniques and scoring system for sleep stages of human subjects.* Washington, DC: National Institutes of Health, 1968. (Publication No 204.)
6 Penaz J. Photoelectric measurement of blood pressure volume and flow in the finger. In: *Digest of the international conference on medicine and biological engineeering.* Dresden: International Conference on Medical Engineering, 1973:104.
7 Boehmer RD. Continuous, real-time, noninvasive monitor of blood pressure: Penaz methodology applied to the finger. *J Clin Monit* 1987;3:282-7.
8 Parati G, Casadei R, Groppelli A, Di Rienzo M, Mancia G. Comparison of finger and intra-arterial blood pressure monitoring at rest and during laboratory testing. *Hypertension* 1989;13:647-55.
9 Penzel T, Ducke E, Peter JH, Podzus T, Schneider H, Stahler J, *et al.* Non-invasive monitoring of blood pressure in a sleep laboratory. In: Ruddel H, Curio I, eds. *Non-invasive continuous blood pressure measurement.* Paris: Peter Lang, 1991:95-106.
10 Smith NT, Wesseling KH, de-Wit B. Evaluation of two prototype devices producing noninvasive, pulsatile, calibrated blood pressure measurement from a finger. *J Clin Monit* 1985;1:17-29.
11 Johnson LC, Lubin A. The orienting reflex during waking and sleeping. *Electroencephalogr Clin Neurophysiol* 1967;22:11-21.
12 Williams HL, Hammack JT, Daly RC, Dement WC, Lubin A. Responses to auditory stimulation, sleep loss and the EEG stage of sleep. *Electroencephalogr Clin Neurophysiol* 1964;16:269-79.
13 Broughton RJ, Poire R, Tassinari CA. The electrodermogram (Tarchanoff effect) during sleep. *Electroencephalogr Clin Neurophysiol* 1965;18:691-708.
14 Ringler J, Basner RC, Shannon R, Schwartzstein R, Manning H, Weinberger SE, *et al.* Hypoxemia alone does not explain blood pressure elevations after obstructive apneas. *J Appl Physiol* 1990;69:2143-8.
15 Shimada K, Kawamoto A, Matsubayashi K, Nishinaga M, Kimura S, Ozawa T. Diurnal blood pressure variations and silent cerebrovascular damage in elderly patients with hypertension. *J Hypertens* 1992;10:875-8.
16 Verdecchia P, Schillaci G, Guerrieri M, Gatteschi C, Benemio G, Boldrini F, *et al.* Circadian blood pressure changes and left ventricular hypertrophy in essential hypertension. *Circulation* 1990;81:528-36.
17 Parati G, Pomidossi G, Casadei R, Malaspina D, Colombo A, Ravogli A, *et al.* Ambulatory blood pressure monitoring does not interfere with the haemodynamic effects of sleep. *J Hypertens* 1985;3(suppl 2):107-9S.
18 Schwan A, Eriksson G. Effect on sleep—but not on blood pressure—of nocturnal non-invasive blood pressure monitoring. *J Hypertens* 1992;10:189-94.

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ONE HUNDRED YEARS AGO

THE COST OF SMALL-POX.

The *Westmorland Gazette* of June 9th furnishes us with a useful contribution towards this information which we are gathering from various sources. It tells the ratepayers in the Sedbergh Union what the recent small-pox cases at Millthorp have cost them. Two cases were discovered in April last year. After being treated for some time in the lodging house where the outbreak occurred, the patients were removed to a temporary hospital erected on the Riggs, and a nurse obtained to attend upon them. Gibson, one of the men, was discharged in June, while the other man, Scott, remained in the hospital until November. The maintenance of the patients and nurse, cost of disinfectants, etc., during this time amounted to £103 8s. 1d., while the iron building, furnishing, etc., cost £157 14s. 3d. This outlay was not a separate charge against Sedbergh township but was spread over the union, and resulted in a rate of about 2½d. in the pound. In addition to the above cost, Dr. Thorburn, the medical officer, claims a large sum for attendance. (*BMJ* 1894;i:1320.)