Computers in Biology and Medicine 43 (2013) 900–903

Contents lists available at SciVerse ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/cbm

The precision of resting blood pressure measurement

Christopher J. Bailey *

Department of Biochemistry, Trinity College, Dublin 2, Ireland

A R T I C L E I N F O

Article history:
Received 14 July 2011
Accepted 13 April 2013

Keywords:
Blood pressure
Non-linear regression
Standard error
Systolic
Diastolic

A B S T R A C T

By analysis of timed series of blood pressure(BP) measurements from a single individual, it was shown that data-averaging did not usually give a true value of resting systolic or diastolic pressure. Such measurements fitted a pattern of first order decay from an initial pressure towards a resting systolic or diastolic pressure, P. Using non-linear regression analysis it was possible to approach a standard error of 1 mmHg/1 mmHg for P values on a single day; the between-day dispersion, over a period of months, was found to be about 2 mmHg/2 mmHg. Computer analysis is required to give values of resting systolic and diastolic BP accompanied by error estimates.

1. Introduction

Blood Pressure (BP) varies with activity. However blood pressure measured at rest (usually indirect measurement of arterial arm pressure of a relaxed subject by means of an inflatable cuff, with results in mmHg, noted as systolic/diastolic), has been used as as an indicator of human health for over 100 years. Studies convincingly demonstrate the link between single BP measurements and factors such as death rate, by comparing subject and control groups of many thousands of subjects; it can be shown that the differences as small as 2 mmHg of systolic pressure correlate with the real outcomes [1].

Data on individual monitored subjects are usually reported to three figures (systolic) or two figures (diastolic). Scientifically, the notable feature about such accounts is the absence of any uncertainty value, although the presentation implies that use of the final figure (quotation to 1 mmHg) is appropriate.

In the clinical literature there appears to be some disagreement about accuracy. Many experienced workers have clearly reported individual measurements rounded to 10 mmHg/10 mmHg or 10 mmHg/5 mmHg, scientfically unexceptional if the errors are above 5 mmHg/5 mmHg or 5 mmHg/3 mmHg, but unacceptable to those who consider the overabundant terminal zeros and fives as a 'bias' [2].

In collections of data from different eras, some average measures of single-subject between-day BP dispersion (re-estimated by the current author from absolute differences or standard deviation of differences) have standard deviations of 10 mmHg/7 mmHg [3], 10 mmHg/6 mmHg [4] and 7 mmHg/5 mmHg [5]. These are population averages: it is clear [6] that the dispersion increases with measured BP.

The dispersions imply that it can be scientifically acceptable to round single measurements and quote BP values to 10 mmHg/5 mmHg or 10 mmHg/10 mmHg. On the simplest interpretation of dispersion, more exact values for individual subjects would be available by replication.

Medical opinion, however, appears to have lost confidence in the validity of professional measurements and endorsed a preference for amateur 'home BP' values [7]. This preference seems to result from the need to avoid a bias produced by the clinical situation, in which many individuals appear to remain in an alerted [6] state with consequent raised BP.

To determine resting systolic or diastolic BP as conventional scientific parameters, it is necessary to analyse a series of BP measurements. Because the measurements may sample resting state and alerted states, simple data-averaging may not give an exact value of the resting BP parameters. Rather, it seems that an improved data analysis procedure may be required in order to obtain values, and error estimates, of the resting BP parameters. Accordingly extensive self-test progress curves from a single subject (CJB) were analysed to devise a procedure that can give values of the resting BP parameters, together with error estimates.

2. Methods

Blood pressure was measured with a recommended [8] automated oscillometric instrument A&D UA-767, in accordance with the manufacturer's instructions. This upper-arm instrument was inflated to an arm pressure of 180 mmHg before obtaining systolic and diastolic values during deflation. The accuracy of the instrument is quoted as ±3 mmHg/±3 mmHg. Measurements took place when

* Tel.: +35318961608.
E-mail address: cbailey@tcd.ie

0010-4825/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.compbiomed.2013.04.016

the untreated subject (male, aged 68 y, in general good health) was alone in a domestic situation. Data was collected between 10 am and 12 pm, with the subject seated in a reproducible position, after at least 15 min rest and at least 30 min after eating/drinking. The instrument requires about 50 s to register systolic and diastolic pressures and pulse. The measurements were typed into a spreadsheet immediately after registration. Repetition at 1.25 min intervals was found suitable to accumulate data whilst maintaining the subject in a relaxed state. As a further aid to postural relaxation, the arm-cuff was released and reset after every four readings. All measurements were obtained by self-test of the author and there was therefore no further need for ethics approval.

Data were analysed by Excel spreadsheet programmes, notably Solver (fitted with the Solveraid macro [9] to determine standard errors). Results of the non-linear regression (NLR) procedure were confirmed using the econometric package, Gretl [10]. This latter procedure was also used for time-series analysis [11], to calculate autocorrelation functions of BP data streams.

3. Results

In a preliminary investigation, 12 consecutive measurements were obtained in a 15 min period on 8 separate days. When the daily BP measurements were plotted against time, three systolic and two diastolic progress curves had significant ($p>0.95$) negative slopes; the remainder could be interpreted as variation about a mean or having a negative trend; none showed a rising trend. Averaging of such daily data is not generally appropriate. A suitable equation that describes the observed behaviour is

$$BP = A_0 \exp(-\lambda t) + P + \varepsilon \tag{1}$$

In this, each systolic or diastolic BP measurement varies with time t, as set by parameters A_0, an initial overpressure; λ, a decay constant; and P, a stationary pressure that may correspond to the resting state. Eq. (1) fits data that oscillates about P according to the value of the random error term ε; that decays during the period of measurement to an asymptotic value of P; or that decays continually without establishing a stationary P. NLR data fitting to minimise the sum value of ε^2 provides an objective least-squares choice between the three possible outcomes.

When applied to the 12 measurements by 8 days, NLR gave realistic systolic or diastolic P values with data from four of the days, but the four others produced impossibly low, or only very inexact, values of P. It appeared that the time period, or number of measurements, was insufficient for reliable establishment of a stable P value.

The repetitive measurements were therefore extended to 30 min (data sets 1–5), and later, after a gap of about two months, to 30–60 min (data sets 6–17). The set numbers correspond to the following dates in 2010: 1, 29-Mar; 2, 30-Mar; 3, 31-Mar; 4, 1-Apr; 5, 2-Apr; 6,28-Jun; 7, 29-Jun; 8, 3-Jul; 9, 13-Jul; 10, 15-Jul; 11, 16-Jul; 12, 17-Jul; 13, 19-Jul; 14, 20-Jul; 15, 21-Jul; 16, 22-Jul; 17, 23-Jul. A total of 17 days data was obtained, about 600 measurements each of systolic and diastolic BP.

The systolic and diastolic data were initially fitted individually to Eq. (1), but set 9 data proved particularly difficult to fit objectively. As the paired systolic-diastolic BP measurements are highly correlated (paired systolic-diastolic values of A_0 and P are also correlated and can supply supplementary constraints), it is appropriate to take the value of decay rate λ as common to a systolic–diastolic pair. This gave a more forceful and universal fitting process in which residual sum of squares (weighted to give equal value to systolic and diastolic members) was minimised to give five parameters, rather than a total of six when diastolic and systolic data are fitted separately (all Figures show the data fits from the paired λ procedure). The estimated values of P did not significantly change: the average differences of P between the separate and combined procedures estimates were 0.5 ± 2 mmHg/0.3 ± 0.9 mmHg ($n=16$ pairs).

Twelve of the systolic–diastolic paired records were interpretable as a decay from a substantial initial overpressure to an asymptotic stationary pressure (e.g. Figs. 1 and 2, the respective systolic and diastolic data from set 6), in which the data points are shown with the best fit (stippled line) to Eq. (1). In four other paired records, the initial overpressure effects were so low (a bias of $<+.5$ mmHg/$+.5$ mmHg) that averaging of the data was also appropriate (illustrated in Figs. 3 and 4, the respective systolic and diastolic data from set 14).

The remaining record of the total of seventeen, illustrated by Fig. 5, gave a more complex pattern that did not fit to Eq. (1). During this set, the subject was alerted by his small timing error at 15 min. Within 1.25 min the perturbation produced a transient rise in systolic and diastolic (not shown) BP. The data set was satisfactorily modelled by adding terms for transient overpressure at 16.25 min and subsequently.

The values of systolic and diastolic parameter P, in each of the 17 pairs, are presented in sequence in Figs. 6 and 7, which include the four paired cases calculated by NLR and by simple averaging. It seems clear that the fitted daily systolic and diastolic P values did not change systematically over the course of the experiments. Between-days systolic and diastolic P mean values were calculated for weighted (weights proportional to the reciprocal of the square of the standard error) and unweighted conditions: mean values ($\pm$standard deviations) were 134.6 ± 2.4 mmHg/80.8 ± 2.0 mmHg ($n=17$), and 132.3 ± 4.7 mmHg/80.4 ± 2.8 mmHg for weighted and unweighted estimates respectively. Inclusion of the four day-averaged values from time-

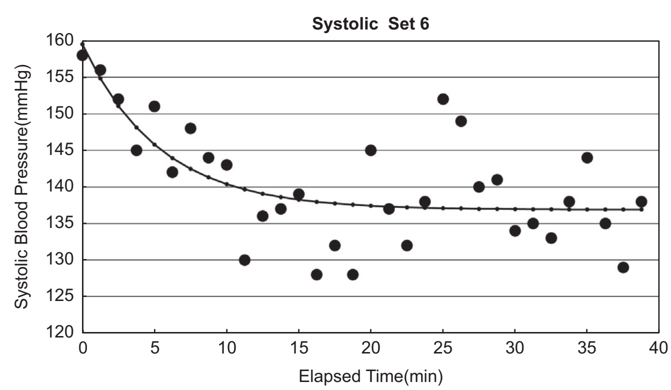

Fig. 1. Systolic pressure measured in set 6. The measured data (circles) are graphed together with a line calculated from the best fit to Eq. (1).

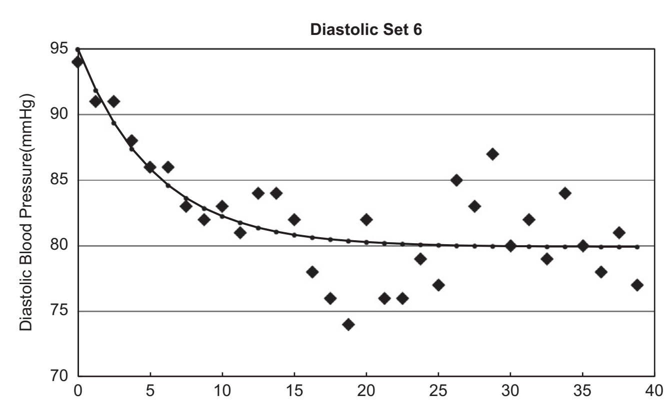

Fig. 2. Diastolic pressure measured in set 6.