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Patrick Mitchell, Barbara Gregson, Ian Piper, Giuseppe Citerio, A David Mendelow and Iain R Chambers

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Patrick Mitchell[*], Barbara A Gregson*, Ian Piper[+], Giuseppe Citerio[#], A David Mendelow[*] and Iain R Chambers[§] on behalf of the BrainIT group.
[*]Department of Neurosurgery and [§]Regional Medical Physics Department, Newcastle General Hospital, Newcastle upon Tyne, NE4 6BE, UK
[+]Department of Clinical Physics, Institute of Neurological Sciences, Southern General Hospital, Glasgow, G514TF, UK
[#] Department of Perioperative and Intensive Care, Neuro Intensive Care Unit, Hospital San Gerado, Monza, Italy.

Address for correspondence
Dr IR Chambers
Regional Medical Physics Department
The James Cook University Hospital
Marton Road
Middlesbrough, UK, TS4 3BW
email i.r.chambers@ncl.ac.uk

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Abstract

Objective
To determine the statistical characteristics of blood pressure readings from a large number of head injured patients.

Methods
The BrainIT group have collected high time resolution physiological and clinical data from head injured patients who require intracranial pressure (ICP) monitoring. We have examined the statistical features of this data set of blood pressure (BP) measurements with time resolution of up to 1 minute from 200 patients. The distributions of blood pressure measurements and their relationship with simultaneous ICP measurements are described.

Results
The distributions of mean, systolic and diastolic readings are close to normal with modest skewing towards higher values. There is a trend towards an increase in blood pressure with advancing age but this is not significant. Simultaneous blood pressure and ICP values suggest a triphasic relationship with a BP rising at 0.28mmHg / mmHg of ICP for ICP up to 32mmHg, 0.9mmHg / mmHg of ICP for ICP from 33 to 55mmHg and falling sharply with rising ICP for ICP over 55mmHg.

Conclusions
Patients with head injury appear to have a near normal distribution of blood pressure readings that are skewed towards higher values. The relationship between BP and ICP may be triphasic.

Introduction

Since its introduction in the 1960s[1], invasive blood pressure (BP) monitoring has become an important part of patient management in high dependency and intensive care units. Despite widespread use of the modality[2], few large data sets are available indicating its statistical features. Here we present the results of invasive blood pressure measurements made in 200 patients who were being treated for head injury.

These data have become available as a result of the BrainIT project that was conceived in 1997 and has grown into an international collaboration[3] with the purpose of gathering data on the physiological parameters and treatments associated with significant head injuries with high time resolution. Over the period between 1998 and 2006 data capture systems were deployed in high dependency and intensive care units in participating neuroscience centres.

The relationship between ICP and BP has been recognised since first described by Cushing in 1901[4]. Several reports since then confirm a positive correlation particularly with higher ICPs[5] during tracheal suction[6] and simultaneous with ICP "B waves" in patients being investigated for normal pressure hydrocephalus[7]. Similar data to these from 80 patients having computerised monitoring of ICH following head injuries showed a positive correlation for ICPs over 25 but not for lower values[8].

The difference between mean arterial and mean intracranial pressure (cerebral perfusion pressure or CPP) has assumed great importance as it is seen as a parameter for therapeutic optimisation in the care of head injured patients. Studies have demonstrated that the relationship between IPC or CPP and outcome both in adults[9] and children[10] alongside the development of guidelines for the management of severe head injury but any influence on improving outcome has yet to be demonstrated.

We describe the distributions of BP measurements, their relationship with simultaneously taken ICP measurements and the characteristics of the patients in whom the measurements were made.

Patients and methods

The primary goal of the EU funded BrainIT project was to collect detailed physiological, clinical and management data from head injured patients who required ICP and intra-arterial BP monitoring as part of their routine care. Twenty four participating centres were initially involved in the study. For each centre electronic equipment was provided for minute-by-minute collection of physiological data and also for the input of details of the clinicall condition of the patients and management measures used. All data were anonymised prior to transfer to Glasgow, converted into a standard format and then entered into a database.

Approval for the study was obtained from the relevant local Ethical Committees and the first patient was recruited in July 2003. Data analyses were performed using Matlab version 6 .5.
At the time of analysis a total of 200 patients had been recruited over a period of 24 months from 21 centres. Their age ranged from 4 to 83 years, with a mean and median of 37 and 33 years respectively, 162 were male and 38 female. The causes of injury were: assault = 17, fall = 56, pedestrian = 16, sport =6, traffic= 85, work = 5 and 15 were unknown.

Presenting Glasgow coma scores were available for 184 of the 200 cases and served as an index of injury severity; they ranged from 3 to 15 with a distribution as shown in figure 1. The number of blood pressure measurements per patient varied widely from 52 to 28,584 with the distribution shown in figure 2. Mean BP measurements were available for all patients. Of these a breakdown into systolic and diastolic BP was available in 171 patients.

The procedures for managing ICP varied between units but all used some treatment in response to adverse changes in measured pressures. Maintenance of ICP under a threshold value or CPP over a threshold value were both used as therapeutic targets in different patients. ICP thresholds ranged from none to 30mmHg and CPP from none to 70mmHg. There was also variation in the duration of pressure excursions beyond these thresholds that were seen as significant. This variation reflects the ongoing debate about the best way to manage raised ICP after head injury.

Some artifactual measurements are to be expected in a data set at this type. In order to minimise the inclusion of these readings measurements outside the credible physiological ranges were excluded. The distribution of measurements was observed and compared with the expected smooth distribution of natural phenomena. The data contains what appeares to be a substantial overrepresentation of values of ICP of between 0 and -20mmHg. And of BP below 20mmHg. These values were excluded because it was assumed that a majority, though not all, were artefactual.

The statistical methods used are mainly descriptive. The points plotted in the figures represent mean values of BP. Confidence limits were calculated using Poisson distributions. The closeness of the distribution of BP data overall to a normal distribution was assessed using quantile v quantile (Q-Q) plots where the quantiles of the data set were plotted on the x axis against quantiles of a theoretical normal distribution with the same mean and variance on the y axis. (figure 4). Standardised third moments were calculated to give a quantitative measure of the amount of skew in the distributions. Least squares linear regression was used on the dataset presented in figure 5 to express BP as a function of ICP over two regions that were identified by visual inspection of the graph.

Results

Blood-pressure distributions

The dataset included 1.6, 1.6 and 1.8 million observations of diastolic, systolic, and mean blood pressures respectively. The distributions of these measurements are shown graphically in figure 3 and summary statistics are given in table 1. All three distributions are close to normal as can be seen in figure 3. Further analysis with Q-Q plots (figure 4) shows that none of the distributions are quite normal, all being skewed towards higher values.

Table 1: Means and Standard Deviations of invasive blood pressure data (mmHg)

	Mean	Standard Deviation	Standardised third moment	No of obs.
Systolic	140.41	23.10	0.36	1557767
Diastolic	66.21	13.78	2.10	1556760
Mean	89.43	16.23	1.74	1814850

Relationship between BP and ICP

Blood pressures may be higher on average in head injured patients than in others. The association between head injury and raised intracranial pressure may produce a reflex hypertension and in some cases therapeutic hypertension is used as a treatment for raised intracranial pressure. Simultaneous data on BP and ICP is available in the BrainIT dataset from 195 patients and shows the relationship between mean intracranial pressure and mean blood pressure (figure 5). There is wide variation in the number of measurements made at different values of ICP which reflects the relative rarity of readings above 35mmHg. The distribution of the number of simultaneous BP and ICP measurements as a function of both BP and ICP is shown in the contour plot of figure 6. This shows a two directional Normal distribution with slight skewing towards high ICP and BP values.

Relationship between BP and age

It is well recognised that BP rises with advancing age. A scatter plot of BP versus age for the patients in this series is shown in figure 7. The slight trend towards an increase in blood pressure with advancing age did not reach significance. 95% limits of the linear relationship between agent BP and of the individual values are also shown on the figure.

Artefacts

Certain features of the dataset suggest artefactual overrepresentation of particular values. The distribution of mean BP observations in the range of -100 to 30 mmHg shows peaks of numbers of observations at -91, -40, -19, and -4 mmHg. These clearly do not represent true physiological measurements. There is a large peak of 9784 data points at the BP of zero which is suspected to be an artefact. These artefactual measurements are excluded from the data presented in figures 3 to 7 and table 1. In the case of ICP measurements there is a peak at zero mmHg of ICP which is believed to be an artefact. It is suspected that the values of 1, 2, 3, and 4mm mmHg ICP are also overrepresented in the dataset. This is indicated by distortion of the distribution of ICP values and also by the first four points on the graph of ICP versus BP (figure 5).

Discussion

The BrainIT dataset is one of the largest of high time-resolution invasive blood pressure in head injury. It was collected in a large number of units from different European countries. Certain features of data distribution analyses such as small deviation from a normal distribution can only be determined from large data sets.

The measurements made in head injured patients should be applied to other patients with caution. The relationship between mean ICP and mean blood pressure shown in figure 6 extends over the range of ICP that would normally be regarded as “normal” of between zero and 15 mmHg[11,12]. Even a population of patients with head injuries and relatively normal ICP may have a slightly raised blood pressure consequent upon changes in ICP within the normal range[13]. Furthermore the effects of the post traumatic stress response and sedation may have influenced the results.

The graph of figure 5 appears to naturally fall into four zones:

for ICP values between 4 and 32mmHg, blood pressure is related by the equation

$$\text{Blood pressure} = 0.28 * \text{ICP} + 84.4$$

for ICP between 33 and 55mmHg this changes to

$$\text{Blood pressure} = 0.90 * \text{ICP} + 61.6.$$

The upswing in the blood pressure values at ICPs of 0, 1, 2 and 3 mmHg may be an artefact as ICP measurements with these low values are overrepresented in the data set as can be seen in figure 7. The over-representation is believed to be quasi-randomly distributed in the data set. This means that the greater the proportion of artifactual readings at a specific value, the nearer the average BP at the value will be to the overall average. This may explain the initial down slope. If this were the full explanation the mean BP with ICP=0 would be expected to be just under the overall average of 89.29 mmHg but is 92.04mmHg. It is interesting to note that the same down slope in BP for the range of ICP from 0 to 3 can be seen in the data reported by Czosnyka et al[8]. The decline in blood pressure over ICP of 55mmHg is probably real and reflects the fact that most cases under these circumstances are suffering from agonal coning.

The relationship between ICP and BP in figure 5 shows a tendency to maintain CPP at or above about 60mmHg. There may be an iatrogenic component to this as maintenance of ICP or CPP were used as therapeutic targets. Physiological effects cannot be distinguished from the effects of treatment aimed at optimising ICP, BP or CPP because patients were selected to receive such treatment on the grounds of changes in the same parameters. It is not possible to separate treatment effects from selection effects in a dataset of this type but it is likely that for ICPs below 20mmHg the effect seen is physiological because there is little reason to pharmacologically increase BP in response to ICP in this region. Of note is that contrary to the findings of Czosnyka et al[8] we have observed a positive correlation between ICP and BP over this region.

Conclusions

Based on invasive blood pressure measurements in 200 head injured adult patients the distribution of blood pressure is not normal but skewed towards high values. The means (and standard deviations) of diastolic, systolic and mean measurements were 66 (13.8), 140 (23.2) and 89 (16.5) mmHg respectively.

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Investigators and Participating Centres

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BrainIT Steering Group members

IR Chambers, Newcastle upon Tyne; G Citerio, Monza; P Enblad Uppsala; BA Gregson, Newcastle upon Tyne; T Howells, Uppsala; Karl Kiening, Heidelberg; P Nilsson Uppsala; I Piper, Glasgow; A Ragauskas, Kaunas; J Sahuquillo, Barcelona and YH Yau, Edinburgh.

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Authors contrubutions

P Mitchell, BA Gregson AD Mendelow and IR Chambers conceived analysis. P Mitchell, BA Gregson and IR Chambers performed the analysis. P Mitchell, BA Gregson, I Piper, G Citterio, AD Mendelow and IR Chambers helped draft the manuscript. I Piper, BA Gregson, G Citterio and IR Chambers are on the Steering Committee of BrainIT. All authors have had access to the all the data in the study and they held final responsibility for the decision to submit for publication.

Figure Legends

Figure 1
Histogram showing the distribution of pre-neurosurgical hospital Glasgow Coma Score.

Figure 2
Histogram showing the distribution of observations per patient. The distinction between mean blood pressure measurements and systolic/diastolic measurements is a consequence of different types of data collection system. All systems that collect systolic/diastolic measurements also calculate means but some only given means and not a systolic/diastolic breakdown.

Figure 3
Line plots showing the distributions of diastolic, systolic, and mean invasive blood pressures measurements.

Figure 4
Q-Q plots of the distributions of systolic (a), diastolic (b) and mean (c) blood pressures. In a Q-Q plot the quantiles measured from the dataset are plotted against the theoretical quantiles of a normal distribution that has the same mean and standard deviation as the dataset. A perfectly normally distributed dataset will have a Q-Q plot along the straight line plotted. The sigmoid deviation from the straight line seen in the three plots, most prominently in the mean plot, indicates skewing towards higher blood pressures.

Figure 5
The relationship between intracranial pressure and blood pressure. Ninety nine percent limits were chosen because 95% limits are too narrow to be resolved over most of the graph. The confidence limits are of the means and are based on Poisson distributions.

Figure 6
Contour plot of the distribution of the number of measurements with both mean BP and mean ICP rounded to the nearest whole number mmHg. Blood pressure is on the vertical axis and ICP on the horizontal axis. For example there were 707 measurements made with a mean ICP off 4 and simultaneous mean BP of 73.

Figure 7
Scatter plot of patient age v mean BP for individual patients. The 95% limits of the mean and values are shown. The slight positive relationship does not reach significance.

References

1. Bevan AT, Honour AJ, Stott FH. Direct arterial pressure recording in unrestricted man. Br Heart J 1969;31(3):387-8.
2. Pinsky MR. Hemodynamic monitoring in the intensive care unit. Clin Chest Med 2003;24(4):549-60.
3. BrainIT. Neurointensive care monitoring research group, 1998: URL: http://www.brainit.org.
4. Cushing H. Some Experimental and Clinical Observations concerning States of Increased Intercranial Tension. (Mutter Lecture, 1901.). 1901.
5. Gobiet W, Grote W, Bock WJ. The relation between intracrainal pressure, mean arterial pressure and cerebral blood flow in patients with severe head injury. Acta Neurochir (Wien) 1975;32(1-2):13-24.
6. Wang MH, Cheng SY, Wang YC, Lee BW, Lin YY, Tseng CL. [The effect of intracranial pressure caused by airway suction in hypertensive intracerebral hemorrhagic comatose patients]. Zhonghua Yi Xue Za Zhi (Taipei) 1993;52(2):109-15.
7. Droste DW, Krauss JK. Intracranial pressure B-waves precede corresponding arterial blood pressure oscillations in patients with suspected normal pressure hydrocephalus. Neurol Res 1999;21(7):627-30.
8. Czosnyka M, Price DJ, Williamson M. Monitoring of cerebrospinal dynamics using continuous analysis of intracranial pressure and cerebral perfusion pressure in head injury. Acta Neurochir (Wien) 1994;126(2-4):113-9.
9. Chambers IR, Treadwell L, Mendelow AD. Determination of threshold levels of cerebral perfusion pressure and intracranial pressure in severe head injury by using receiver-operating characteristic curves: an observational study in 291 patients. J Neurosurg 2001;94(3):412-6.
10. Chambers IR, Jones PA, Lo TYM, et al. Critical thresholds of intracranial pressure and cerebral perfusion pressure in paediatric head injury related to age. Journal of Neurology Neurosurgery and Psychiatry 2006;77:234-240.
11. Williams B. Simultaneous cerebral and spinal fluid pressure recordings. I. Technique, physiology, and normal results. Acta Neurochir (Wien) 1981;58(3-4):167-85.
12. Shapiro K, Marmarou A, Shulman K. Characterization of clinical CSF dynamics and neural axis compliance using the pressure-volume index: I. The normal pressure-volume index. Ann Neurol 1980;7(6):508-14.
13. Schmidt EA, Czosnyka Z, Momjian S, Czosnyka M, Bech RA, Pickard JD. Intracranial baroreflex yielding an early Cushing response in human. Acta Neurochir Suppl 2005;95:253-6.

Figure 1

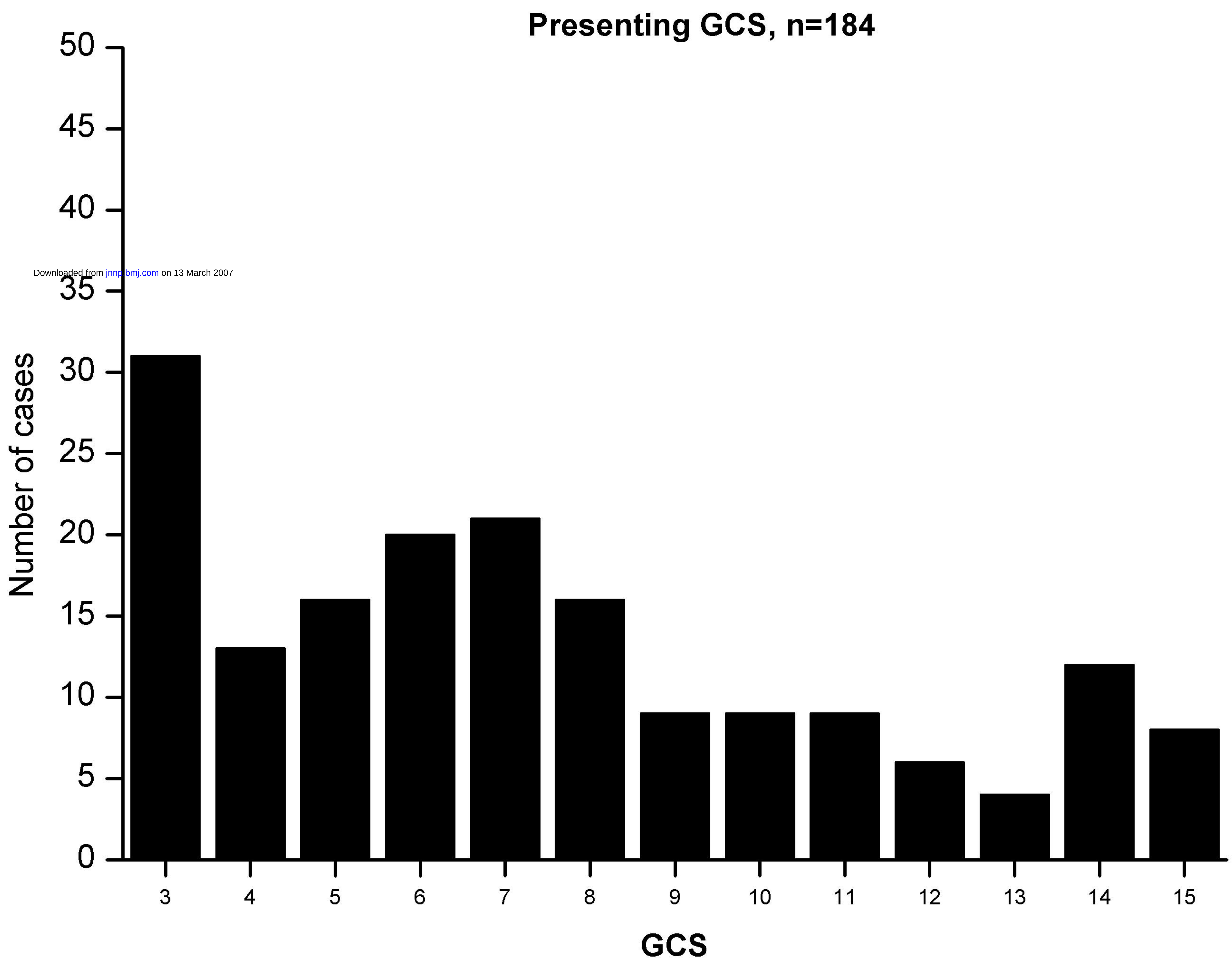

Presenting GCS, n=184
Number of cases
50
45
40
35
30
25
20
15
10
5
0
3
4
5
6
7
8
9
10
11
12
13
14
15
GCS

Figure 2
Distribution of number of measurements per patient, n=200

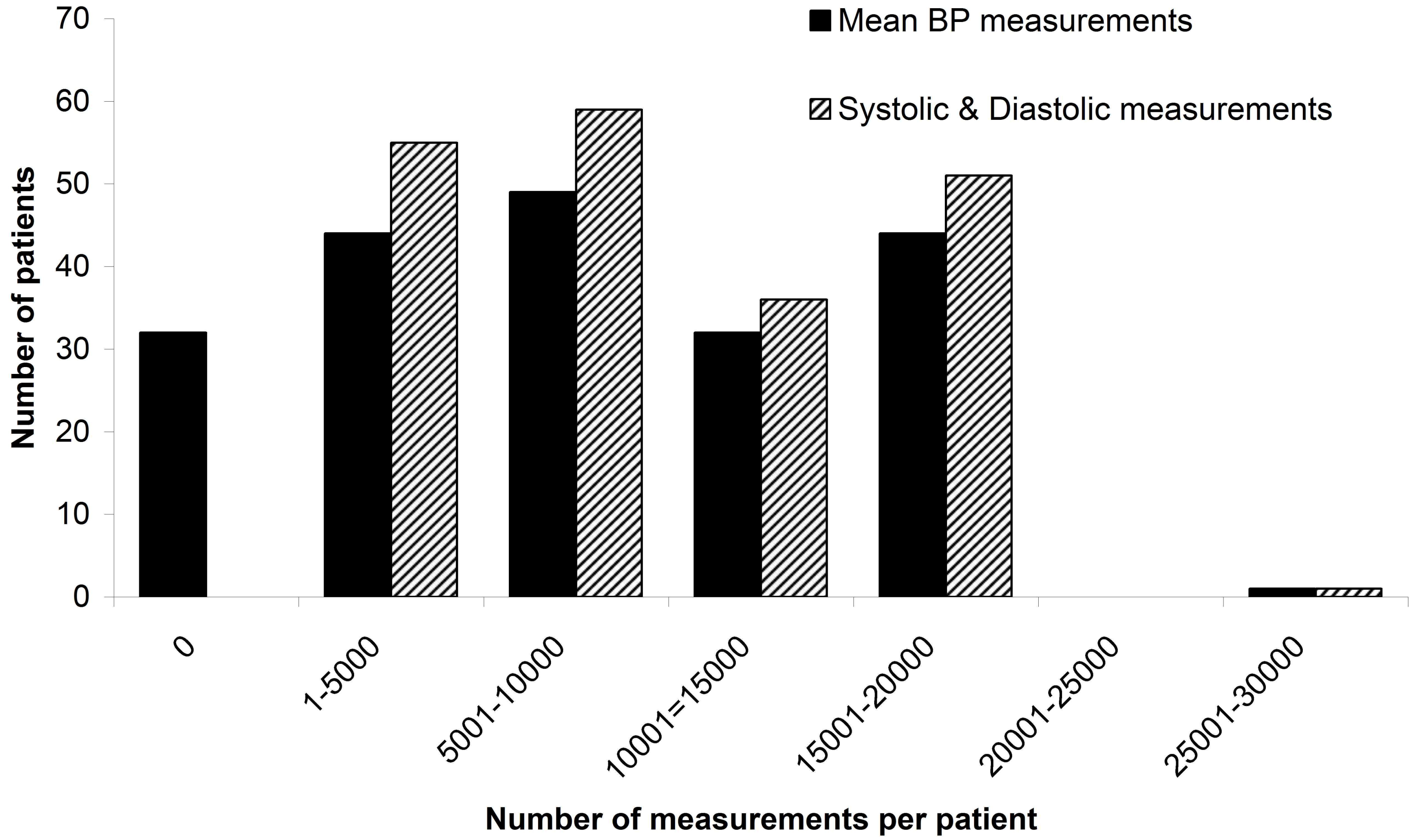


Figure 3
Distributions of BP measurements

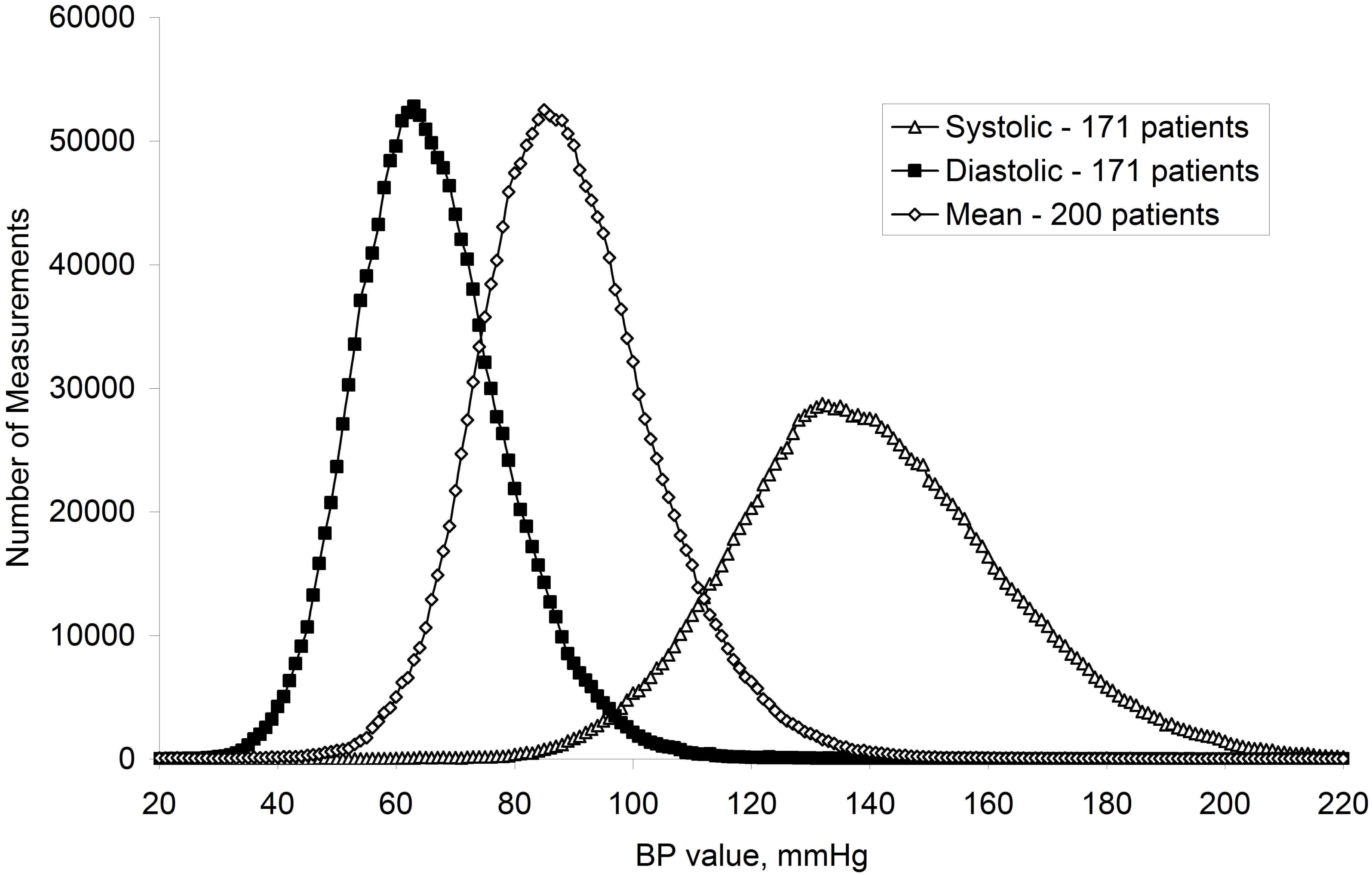
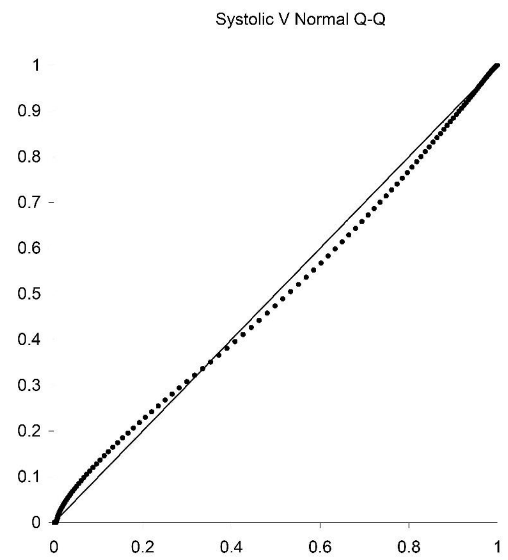
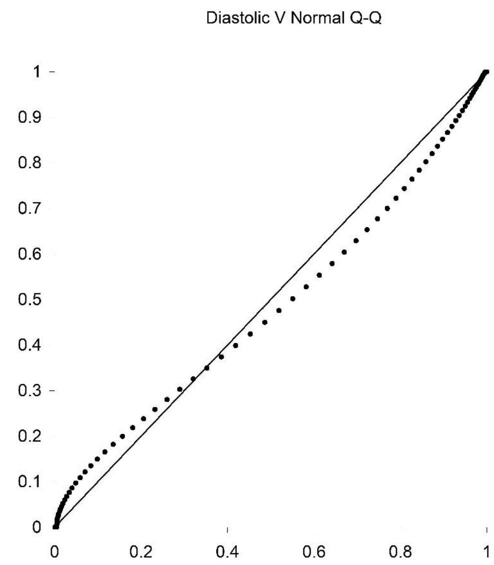


Figure 4
n=200

a



b



c

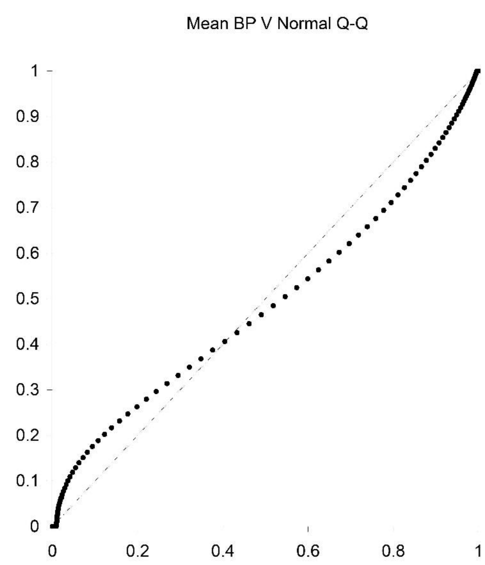


Figure 5
Average BP v ICP
195 patients