

## **The Brain Monitoring with Information Technology (BrainIT) collaborative network: Past, Present and Future Direction**

**Ian Piper<sup>1</sup>, Iain Chambers<sup>2</sup>, Giuseppe Citerio<sup>3</sup>, Per Enblad<sup>4</sup>,  
Barbara Gregson<sup>2</sup>, Tim Howells<sup>4</sup>, Karl Kiening<sup>5</sup>, Julia Mattern<sup>5</sup>,  
Pelle Nilsson<sup>4</sup>, Arminas Ragauskas<sup>6</sup>, Juan Sahuquillo<sup>7</sup>, St.M. Iencean<sup>8</sup>,  
R. Donald<sup>9</sup>, R. Sinnott<sup>10</sup>, A. Stell<sup>10</sup>, on behalf of the BrainIT Group**

<sup>1</sup>Clinical Physics, Southern General Hospital, Glasgow UK; <sup>2</sup>Regional Medical Physics Department, Newcastle General Hospital, Newcastle, UK;  
<sup>3</sup>Neuroranimazione, Hospital San Gerardo, Monza, Italy; <sup>4</sup>Neurosurgery, Uppsala University Hospital, Uppsala, Sweden; <sup>5</sup>Neurosurgery, Ruprecht-Karls-Universität Hospital Heidelberg, Germany; <sup>6</sup>Kaunas University Hospital, Kaunas, Lithuania;  
<sup>7</sup>Neurosurgery, Vall d'Hebron Hospital, Barcelona, Spain  
<sup>8</sup>Neurosurgery, Emergency Hospital "Prof Dr N Oblu" Iasi, Romania; <sup>9</sup>C3 Global Ltd, Dingwall, Scotland; <sup>10</sup>National eScience Centre, University of Glasgow, Scotland  
On-behalf of the Brain-IT Group ([www.brainit.org](http://www.brainit.org)).

### **Abstract**

The BrainIT group works collaboratively on developing standards for collection and analyses of data from brain injured patients and to facilitate a more efficient infrastructure for assessing new health care technology with the primary objective of improving patient care. European Community funding supported meetings over a year to discuss and define a core dataset to be collected from patients with traumatic brain injury using IT based methods. In this paper, we give an overview of the aims and future directions of the group as well as present the results of an EC funded study with the aim of testing the feasibility of collecting this core dataset across a number of European sites and discuss the future direction of this research network. Over a three year period, data collection client and web-server based tools were developed and core data (grouped into 9 categories) were collected from 200 head-injured patients by local nursing staff in 22 European neuro-intensive care centres. Data were uploaded through the BrainIT web site and random samples of received data were selected automatically by computer for validation by data validation (DV) staff against primary sources held in each local centre. Validated data were compared with originally transmitted data and percentage error rates calculated by data category. Feasibility was assessed in terms of the proportion of missing data, accuracy of data collected and limitations reported by users of the IT methods. Thirteen percent of data files required cleaning. Thirty "one-off" demographic and clinical data elements had significant amounts of missing data (> 15%). Validation staff conducted 19,461 comparisons between uploaded database data with local data sources and error rates were commonly less than or equal to 6%, the exception being the surgery data class where an unacceptably high error rate of 34% was found. Nearly 10,000 therapies were successfully recorded with start-times but approximately a third had inaccurate or missing end times which limits the analysis of duration of therapy. Over 40,000 events and procedures were recorded but events with long durations (such as transfers) were more likely to have "end-times" missed. The BrainIT core dataset is a rich dataset for hypothesis generation and post-hoc analyses provided studies avoid known limitations in the dataset. Limitations in the

current IT based data collection tools have been identified and have been addressed. In order for multi-centre data collection projects to be viable the resource intensive validation procedures will require a more automated process and this may include direct electronic access to hospital based clinical data sources for both validation purposes and for minimising the duplication of data entry. This type of infrastructure may foster and facilitate the remote monitoring of patient management and protocol adherence in future trials of patient management and monitoring.

**Keywords:** clinical network, traumatic brain injury, Grid, Internet

## Background

Severe traumatic brain injury is a leading cause of death and survivors have serious and long term morbidity [1]. There are significant social and economic effects including loss of employment and an increased burden of care to the victim their families and society as a whole.

The aetiology of the disease is complex often implicating multiple organ systems causing a high variation in the presentation of injury and, as a result, a large number of patients are required when assessing new health care technology. Recruiting patients from multiple centres will significantly reduce the time to assess new therapies and monitoring devices. However, despite the existence of guidelines for the management of severely head injured patients [2, 3] this group of patients is subject to considerable variability in care across centres [4-9]. To improve the monitoring and management standards in this population, the inter and intra-centre variability in the intensive care management, physiological monitoring and treatment of these patients needs to be assessed on a multi-national basis. To do so requires a standardised, IT based, higher resolution methodology for acquiring multi-centre patient

management and physiological monitoring information.

One consequence of the variability in the clinical management across centres that take care of patients with TBI (traumatic brain injury) is the confounding influence that this may have in multi-centre trials of therapy. Despite promising pre-clinical results of several potential neuroprotective drugs most have failed to show efficacy in the head-injured population. A number of reasons have been proposed for these failures which include: poor study design, insufficient dose of drug penetrating the blood brain barrier and inter-species differences in brain injury mechanisms.

Another factor, not as yet systematically examined, may be the occurrence of secondary insults which are missed through use of inappropriate monitoring methods. Recent estimates put the proportion of adverse events missed by using only end-hour recording compared with minute by minute computer based monitored to be in the region of 30% [13]. Even in large scale randomised trials an accurate sample size analysis cannot be made without a knowledge of the incidence of the true variability of relevant confounding factors. Inaccurate sample size estimates

will lead to trials that are not correctly powered.

Improving the standards and resolution for multi-centre data collection will also effect assessment of new medical technology which is of relevance to the medical device industry. The majority of companies that develop or support devices used to monitor brain injured patients in intensive care are small to medium size enterprises (SME). Unlike the pharmaceutical industry SMEs lack the resources to independently assess their devices in multi-centre clinical trials and this severely limits the ability to provide an evidence base demonstrating the clinical utility of their products.

In order to address these issues it is essential to develop an open, collaborative network of centres interested in the realisation of higher resolution and standardised methods for the collection of neuro-intensive care monitoring and management data from patients with traumatic brain injury. Such an infrastructure will provide a more efficient means for assessing new and developing health care technology which may be new pharmaceutical compounds, management approaches or monitoring devices.

To address these issues, the Brain Monitoring with Information Technology (BrainIT) group was formed ([www.brainit.org](http://www.brainit.org)) . The group has 3 main aims:

1) To develop and disseminate standards for the collection, analysis and reporting of intensive care monitoring and management data collected from brain injured patients.

2) To develop and use a standardised database as a tool for hypothesis generation and the development, testing and validation of new data analysis methodologies.

3) To provide an efficient multi-centre infrastructure for generating evidence on the utility of new invasive and non-invasive intensive care monitoring and management methods.

The BrainIT group have first defined a core dataset collected using PC based tools as part of a European Community (EC) funded study (QLGT-2000-00454). A series of meetings spread over one year enabled key stake holders to meet and the group to define a minimum set of data that should be collected from all patients with traumatic brain injury (TBI). The outcome of the study was to define a core dataset which would be useful in most research projects conducted in this population of patients [10].

This paper reports on the results of a subsequent three year EC funded study (QLGC-2002-00160) that enabled the group to develop IT methods to collect the core dataset and to assess the feasibility and accuracy for collection of this core-dataset from 22 neuro-intensive care centres across Europe. Feasibility was assessed in terms of amount of missing data, accuracy of data collected and limitations reported by users of the IT data collection methods. To assess accuracy, data validation staff (usually research nurses) were hired on a regional basis (normally country by country) to check samples of the collected data against the local primary clinical record in order to quantify the accuracy of the IT based

data collection methods. This paper describes an analysis of the comparison of the data from 200 patients with that obtained independently by data validation staff. The error rates classed by data category are described and the known limitations of current IT data collection methods are considered along with some proposed solutions.

## Methods

### Core dataset Definition

Through European Community (EC) funding (QLRI-2000-00454), a series of meetings over a one year period brought together neurosurgeons, intensivists, scientists and representatives from the medical device and pharmaceutical industries to define and discuss a “core-dataset definition” for data that should be collected from all patients with traumatic brain injury (TBI), irrespective of the underlying project aim. A core dataset was defined and published [10] that consisted of the following nine data categories:

i) Demographic and “one-off” clinical data (pre-neurosurgical hospital data, neurosurgical hospital admission data and the first and worst CT scan data). This data is collected only once per patient.

ii) Daily management data (eg: use of sedatives, analgesics, vasopressors, fluid input/output balance etc). This data is collected as an overview of the day to day intensive care management of the patient and is collected only once per day.

iii) Laboratory data (eg: blood gas, haematology, biochemistry data etc). This is “episodic” data which is data collected more than once but at unpredictable times.

iv) Event data (eg: nursing manoeuvres, physiotherapy, medical procedures (line insertion), calibrations etc - also episodic data).

v) Surgical procedures.

vi) Monitoring data summary (eg: type and placement location of ICP sensor, BP lines, etc). Typically this data is only collected once per patient and is an overview of the monitoring configuration for a patient.

vii) Neuro Event data (eg: Glasgow Coma Score, pupil size and reactivity also episodic data).

viii) Targeted Therapies A set of therapy categories have been defined with some associated therapy type detail. For every therapy given an intended target must also be given (eg: mannitol for raised ICP).

ix) Vital monitoring data. This is bedside monitoring data which is collected at regular intervals with a minimum sampling rate of once per minute.

### Network Structure

The BrainIT group network structure consists of a central coordinating and data centre (Glasgow) with individual centres clustered into language based regions where each language region contains a sub-coordinating centre. Each sub-coordinating centre is responsible for coordinating the training and validation activities across centres within their region and to meet this requirement hire a “data validation” nurse responsible for providing training on the data collection tools and web-services to all centres within their own language region. The data validation nurses also provide a data

checking and validation service coordinated from Glasgow.

#### Data Collection Tools

Clinical data is entered by local bedside nursing staff either on hand held PDA's or on in-house designed JAVA based software running on a PC. In collaboration with Kelvin Connect Ltd [11] the BrainIT core dataset definition was implemented in a flexible and easy to use hand-held PDA based device. A training course was held for the data validation nursing staff in Glasgow on the optimal use of the data collection instruments which also provides data entry in six European languages. An anonymisation routine removed patient identification elements from the collected data and labelled the patient data file with a unique BrainIT study code generated from the BrainIT web-site. A local database held in each centre linked the anonymised data to local centre patient ID information which was needed during the data checking stage of the study. Anonymised data was uploaded via the BrainIT website. A server side data converter tool converted data from centre specific format into a standardised BrainIT data format generating nine data category files which are imported into the BrainIT Microsoft SQL2005 database.

#### Data Validation Process

Figure 1 graphically represents the data validation process. Centre staff enter data using client side tools such as the hand held PDA. Data is uploaded via the BrainIT web-services and a server-side converter formats data into the series of common data format files which are input into the BrainIT SQL database. A

validation request tool residing on the database server randomly samples 20% of the data uploaded for each data category and generates a validation request file for each local data validation nurse listing the timestamps and data items to be checked against local data sources. Data validators move between their designated centres and enter into a data validation tool the requested data items from source documentation held in each local centre. The resulting validation data file is uploaded to the BrainIT data coordinating centre via the website and using data validation checking software tools, the validated data is checked against the data items originally sent from which percentage accuracy data was calculated.

As part of this validation process, and in addition to the categorical and numeric clinical data being checked for accuracy, we also assessed the minute by minute monitoring data. Random samples of monitoring data channels uploaded (eg: ICP, SaO<sub>2</sub>) were selected and validation staff asked to manually enter the hourly recorded values from the nurses chart (or local gold standard data source) for the first and last 24 hour periods of bedside monitoring for a given patient for a given channel. These "validation" values could then be compared with a range of summary measures (eg: mean, median) from the computer based monitoring data acquired from the patient.

#### **Assessing Feasibility**

To assess feasibility, we sought answers to specific questions including:

a) What data cleaning was necessary prior to analysis?

b) What proportion of missing data was found in each data category?

c) How accurate is the data that was collected?

d) What are the known limitations of the existing IT methods for collection of the data?

## Results

### Data Description

Over a two year period, core dataset data (grouped by nine categories) were collected from 200 head-injured patients by local nursing staff. One patient's data was discarded from the cohort as there was less than 4 hours of monitoring data which fell outside our inclusion criteria leaving 199 patients in the feasibility study dataset. Table 1 summarises the key demographic and clinical features of the study cohort. Mean age was 36 years with the usual predominance of male patients in such series. Using the TCDB classification on worst CT, 100 patients were coded with diffuse injury and 60 with mass lesions. Using the extended Glasgow Outcome Scale (GOSe) there were 33 deaths (20%) with 47% good and 53 % poor outcome respectively. Table 2 summarises the quantity of data collected per patient classed by data category. There were 109 "one-off" demographic and clinical data items collected which included pre-neurosurgical (PHSH) and neurosurgical hospital (NSH) data. The majority of the data were "episodic" in nature in that they were collected more than once per patient but at unpredictable times. These data types included "ICU monitoring" categories describing, for example, the location and

type of medical monitoring device placed (eg: right frontal ICP bolt), neurological status (ICU GCS scores/pupil size and reactivity) , therapies delivered, surgeries performed etc. The largest number of data items collected fell within the "Other clinical events" category which included annotations of blood samples, lab results, and other nursing and medical procedures. In this category there was on average greater than 230 recordings per patient. The next most common category of data collected were those of annotations of target driven therapies. In this category there were on average greater than 60 targeted therapies delivered per patient. By far the largest category of data collected was the "periodic" minute by minute physiological monitoring data with over 2 million records in the patient cohort. Table 3 lists the number of patients with specific types of monitoring. Figure 2 is a histogram plot showing the quantity and spread of time-series data for the main monitored channels: ICP, BP, CPP, CVP, SaO<sub>2</sub>, Core Temperature, ETCO<sub>2</sub> and PtiO<sub>2</sub>. The number of data points sampled per channel ranges from 89,524 for PtiO<sub>2</sub> to 1.98 million samples for BPm. (BPm = 1,979,284, ICPm = 1,748,423, CPP= 1,719,166 , CVPm= 541,524, SaO<sub>2</sub> = 1,656,614 , Tc = 1,372,641, ETCO<sub>2</sub> = 502,524, PtiO<sub>2</sub> = 89,524.

### **Data Cleaning**

On average three raw data files were uploaded per patient giving 600 patient data files uploaded to the central database using the BrainIT web-services. All data files were validated prior to inclusion into the study dataset and in a proportion of these errors were found with data values needing to be re-checked and corrected by local nursing staff. Seven raw data patient files required resolving mismatches between physiological data patient identifiers and other clinical data files (1.2 % of files uploaded). Ten raw data files required trimming of physiological data outside the range of clinical data (2% of files uploaded). Nineteen patient files required correction of one or more admission, surgery or discharge time stamps (3% of files uploaded).

### **Missing Data**

#### **One-Off Measurements**

There was missing data across certain data fields. Figure 3 is a graph listing those “One-Off” demographic and clinical data fields with greater than 15% of missing data. Common patterns in the types of fields yielding the highest missing data rates could be identified: A) One third of the fields with significant amounts of missing data were “one off” laboratory data values (eg: glucose, Haematocrit, PaCO<sub>2</sub>) which should have been obtained from admission notes from either the pre-neurosurgical hospital (PNSH) or the receiving neurosurgical hospital (NSH). B) One third of the missing fields were explanatory variables associated with either the first or worst CT scan classification. These explanatory

variables included “yes/no” categories as to whether or not specific pathologies were seen on CT such as SAH, pneumoencephalopathy, hydrocephalus etc. C) Fifteen percent of the missing data fields were explanatory variables associated with the 6 month Glasgow Outcome Scale data. These included fields such as “who was the main respondent” to the questionnaire and what was deemed to be the “main cause of disability” (head injury or systemic injury).

#### **Episodic Measurements**

These data types include therapies, laboratory values and nursing and medical procedures that were entered more than once at un-predictable times. For each episodic data measurement both a “start-time” and “end-time” should have been recorded for each measurement by local nursing staff. Nearly 10,000 therapies were successfully recorded with start-times but approximately a third had missing end times. Table 4 is a breakdown of the therapies delivered classed by type listing the proportion with missing “end-times”. Clearly the quantity of missing end-times in this part of the dataset severely limits analyses assessing duration of therapy. Over 40,000 events and procedures were also recorded but events with long durations (such as transfers outside of the ITU for theatre or CT scan) were more than twice as likely to have “end-times” missed. These shortcomings in the acquired episodic data have implications for the design of future data collection/validation tools as well as project training procedures.

### Data Accuracy

In total, 19,461 comparisons were made between collected data elements and source documentation data by data validation research nurses. The number of comparisons made per data category were in proportion to the size of the data received for that category with the largest number checked in laboratory data (5,667) and the least in the surgery data (567) (Figure 4). Table 5 summarises error rates by data class. Error rates were generally less than or equal to 6%, the exception being the surgery data class where an unacceptably high error rate of 34% was found.

In the surgery data category, nursing staff had to choose surgical procedures from a fixed list of procedure types: i) ICP placement, ii) Evacuation of Mass Lesion, iii) Elevation of depressed skull fracture, iv) Removal of foreign body, v) Anterior Fossa repair for CSF Leak, vi) Placement of Extra Ventricular Drain, vii) Active external decompression (with bone removal and duroplastia), viii) Other. This classification system was used in an attempt to simplify and reduce the burden of data entry. However, through discussions with local nursing and data validation staff it was found that there was particular confusion over when to record ICP sensor placement and the presence of skull fractures as the primary surgical procedure. Typically, these procedures occur during the same operative procedure as for example during “evacuation of a mass lesion”. Confusion over coding these two procedures between the original data entry nurse and

the validation nurse accounted for the majority of errors in this data category.

The detection rate of acute events was also examined (eg: nursing management, physiotherapy, blood samples etc). It was found that short duration events were rarely missed but longer duration events such as transfer to CT or theatre were more likely to be not recorded. Through discussions with local nursing and data validation staff it is believed that the intense nursing activity just prior to and following a transfer is more likely to lead to omissions in recording these events on research systems.

Finally, we tested the accuracy of the minute by minute monitoring data that was collected. Table 6 shows the monitoring data validation results for the 6 data types with the most recorded nursing chart values. Data is expressed in terms of bias (+- 95% CL) between the nurses chart recorded values against the computer collected end hour averages. It can be seen from this data that the computer collected end hour data is an accurate reflection of the nurse’s chart recorded data.

As an example, Figure 5 shows a scatter plot of computer monitored minute by minute ICP data averaged over 60 minutes (ICPavg) plotted against nurses chart end hour values (ICPvalid) collected by the data validation nurses. There is a good correlation between the two sets of data with a linear regression best fit R<sup>2</sup> value of 0.9773. Figure 6 is an Altman and Bland plot showing the average bias (-0.15 mmHg) and 95% confidence limits (0.12, -0.45) for the computer monitored end hour averaged



data Vs the nurses chart end hourly recorded values collected by the validation nurses.

### **IT Tool Limitations**

The PDA data entry tool and the website-upload tools did not incorporate sufficient validation mechanisms. Many fields with the PDA tool allowed export and upload of empty data fields. Although most IT technology nowadays can be configured to explicitly specify required fields and prevent upload of data with specific missing data, at the time this study was designed, such validation facilities were not available off the shelf. Also, the PDA tool was designed to allow acceptance of new items not part of the drop down selection menu, which could generate multiple terms for the same data element. This caused added burden on the cleaning process to consolidate multiple text terms for the same data element. The most challenging limitation found with the IT technology used in this study was an inability to automatically track “continuous” (non-bolus) therapies which were started to ensure that a matching “end-time” was entered. This resulted in approximately 1/3rd of the therapies annotated to have missing end times.

### **Discussion**

This project has studied the feasibility for collection of the BrainIT core dataset using our first generation IT based tools. Feasibility has been assessed in terms of amount of missing data, data accuracy for data that was collected and also in terms of identifying limitations in the IT technology used to collect the data.

Good laboratory practice dictates that as part of clinical trial design, acquired data must be checked for accuracy against the primary data sources. This is often implemented through either employing a contract research organisation or independent research nurse staff to perform this duty. In large multi-centre clinical trials, costs to hire research nurse data validation staff can become prohibitively expensive and feasible only if significant industry or research council funding support is provided. Now with the adoption of the new medical device standard ISO-14155, even small medical device studies are expected to provide some form of check on the accuracy of data collected even as part of a non-regulatory post-marketing study.

To our knowledge, this study conducted by the BrainIT group is one of only a few multi-centre projects to attempt to prospectively assess the data capture error rate within an academic investigator led environment [12].

#### **Monitoring Data Validation**

We have shown that computer collected minute by minute vital signs data, summarised as end hour averages, correlated well with nursing chart end hour recordings. This allows for the end hour averaged computer records to be used in database analyses that aim to assess nurses chart recorded detection of events with computer based sampling. Although, end-hour average data correlates well with the nurses hourly recorded value, this does not indicate that important features of the data are not being missed by employing only hourly recording. For example, Zanier and

colleagues [13] conducted a study showing that although computer-monitored end-hour data is accurately reflected by the nurses' chart value, more complex summary measures (such as the detection of an intracranial pressure (ICP) of more than 20 mmHg) are less accurate. Their finding that at least one-third of secondary insults for raised ICP are not identified from the nursing chart is similar to that reported by Corrie and colleagues [14], who also found a similar detection error rate for other signals such as blood pressure, particularly the events of shorter duration. Importantly, Zanier's paper has further shown that when data are categorised in terms of percentage of time spent with raised ICP, the patients exhibiting instability in ICP were most prone to under estimation of ICP insults. The data sampling rate may be pertinent here: Zanier's study sampled at 600 samples per minute, whereas other studies used 1 sample per minute [14] or as few as 4 samples per hour [15]. Our results here confirm those of other investigations showing that the end hour averaged computer values can be used as estimates of nurse's paper based end hour recordings and opens up the possibility for further studies assessing the clinical influence of missed short term adverse physiological events without requiring tedious recording of nursing chart values.

However, the key question remains unanswered as to whether missed adverse events using higher resolution sampling significantly influences clinical outcome. Work conducted by Chambers and colleagues may be relevant in this regard [16]. They found that in studies of

children with TBI, the choice of summary measure is also important. They used an index termed the "Pressure Time Index (PTI)", which is a composite index taking into account both the duration of the adverse event and the degree of physiological impairment below a given threshold. They found, using ROC analysis of the influence of cerebral perfusion pressure adverse events upon clinical outcome (calculated using an age-related PTI index in children), that models that included the PTI measure of CPP burden significantly improved the fit to clinical outcome compared with models that did not include measures of physiological instability. These results are in contrast to those published by Signorini et al who they found very little improvement in outcome prediction when "Insults" are added to the usual clinical features in prognostic models of patient outcome [17]. The approach developed by Chambers and colleagues needs to be repeated in the adult TBI population and is one of the planned analyses on the BrainIT dataset.

#### **Validation Costs**

These validation results calculated on a subset of patients provides an estimate of the data quality on a larger patient cohort of 350 patients collected using the same methodology but collected outside of the validation study. However, future data collection projects will generate datasets under differing data collection conditions and will require a separate validation stage if we wish to maintain our confidence in the level of data collection accuracy. The approach used by the BrainIT group to validate data (using 20% sampling of

uploaded data with some automation of generating data lists for validation) still requires significant research nurse time to track down and enter data for validation purposes. To maintain a full time data validation nurse across all participating countries costs in excess of 1 Million Euro's per year. Such large overheads for an academic network is prohibitively expensive and not sustainable and a more cost-effective solution for data validation must be found.

One promising approach now being assessed by the BrainIT group is developing collaborative research with experts in Grid based middleware technology. Grid technology comes in a variety of forms and covers more than just access to networks of high end servers in order to solve computationally intensive problems. There is a considerable amount of expertise and open source middleware software solutions now available that provide secure access to distributed medical datasets so that the right people see the correct data in the appropriate context [23]. Such an approach, provided local IT policy staff are satisfied with the system security, will enable remote data validation systems to directly query hospital based primary data sources for the purpose of checking the quality of previously uploaded data. Most research datasets contain large portions of data elements that are collected for routine patient management purposes and the difficulty of accessing hospital based data sources often means that research nurses are employed to re-enter data extracted from local hospital sources into research data entry systems. This results in a high

proportion of double data entry which is an inefficient use of nursing resources. Using Grid technology to interface directly with local hospital data sources will reduce the burden of double data entry. Clearly some data validation staff will still be required to support system queries but increased use of automatic data validation procedures and access to hospital based datasets should significantly reduce the cost burden to conduct multi-centre clinical trials. Towards this end, the BrainIT group as part of an EC funded framework VII project are now assessing such an approach in a group of neuro-intensive care centres equipped with the latest Grid technology. This project – the AVERT-IT project [18] has installed Grid services behind hospital firewalls in six BrainIT neuro-intensive care units. Grid services will interface to local hospital systems, extract data which maps to the BrainIT core dataset and integrate data from both hospital sources and local AVERT-IT data collection tools (for those elements not collected as part of routine management) into a local database. Once every 20 minutes, data is stripped of patient identifiers, encrypted and “pushed” out of local hospital networks to an external secure server cluster hosted at the University of Glasgow National eScience Centre [19]. Local databases will be maintained which link local patient identifiers with an anonymous patient identifier. Systems running at the BrainIT coordinating centre in Glasgow allow remote monitoring of the data acquired from all six participating BrainIT centres. Such a remote monitoring service in

quasi real-time (updates every 20 minutes) will allow more efficient collection and validation of hospital based data collected for research purposes while the patient (and their notes) are still within the ITU environment. This infrastructure will also support monitoring of patient management for adverse events (such as treatments given for arterial hypotension) and will enable testing and tracking adherence to study protocols.

### **Lessons Learned**

A number of lessons have been learned during this feasibility study. First, our surgery classification definition is ambiguous. Specifically our definition document did not make it clear how to decide which surgery is the “Primary Reason for Surgery”. For example if a patient undergoes surgery for removal of a mass lesion and repair of depressed skull fracture, some approach must be used to provide a consistent classification response. We are proposing a modified surgery classification to include a “major surgery choice matrix” where individual surgery types are weighted and specific combinations that do occur can be resolved to a single surgical priority.

Secondly not all staff favoured use of a PDA type data tool. By the end of the feasibility study,

approximately half the centres collecting data preferred to use PC based systems rather than the hand-held PDA's. Increasingly, nursing and medical staff have good IT and data entry skills and as a result we have developed new PC based data collection tools. Also, our data tools (although state of the art at the time), did

not provide sufficient local validation features such as preventing export and upload of empty data fields. Most IT technology nowadays can be configured to explicitly specify required fields and prevent upload of missing or incorrect data. Our current generation of data tools now almost entirely allow only specific choices to be made from drop-down “combo boxes” where the default choice is set to a text value of “not set”. This makes it explicitly clear that a given field has not been entered. Our data schema will not allow mandatory fields to be left “not-set” before a patient is discharged from the system. For the entry of treatment information, every treatment must be assigned a specific target and again, the data schema will not accept treatments that have not been assigned a target. Furthermore, our next generation data collection tools, as implemented in the AVERT-IT project, allows annotation of any treatment or procedure with only two mouse clicks providing more rapid and efficient data entry for the bed side nurse. The web-client software now includes data validation routines which will prevent upload of missing data in any required fields. Patients cannot be fully discharged from the system until all required data is entered. Patients with missing data can be partially discharged from the system (when they are discharged from the ITU) but they remain in a visible list “Patients with Missing Data”. A single web page displays all missing fields in red and must be completed before the patient can be fully discharged.

### **Current Status and Future Direction**

The aims of the BrainIT group and their implementation is a staged process. We have successfully defined a core dataset standard, developed some standardised IT tools to collect the core dataset and tested the feasibility for collection of the dataset from 22 centres across Europe. Limitations in our methods have been found and attempts have been made to address those issues prior to starting future studies. Inevitably, with each new project, problems will arise and solutions will be found in a cyclical process. Our second aim "To develop and use a standardised database as a tool for hypothesis generation and the development, testing and validation of new data analysis methodologies." has been achieved and a number of publications are now arising from access to this shared resource [20]. We are currently using the 2nd database release with a third release planned, and what is encouraging is that the existence of the database resource was directly responsible for generating and testing the hypothesis about application of Bayesian neural network methods for prediction of arterial hypotension adverse events which lead to a project now funded under the VIIth EC information and communications technology framework [18].

One of the papers arising from the work of the BrainIT group was a report on its own internal survey of patient management which indicated that international management guidelines are for the most part adhered with [9]. However, there is a risk with surveys that there may be differences in results

between what users believe to be the management applied in their centre and studies which measure it directly. In this regard, a recent paper published by one of our collaborators on analyses of the BrainIT dataset was to assess, subsequent to the BrainIT survey, whether the use of hyperventilation therapy for the management of raised ICP was indeed conducted according to international guidelines. Interestingly they found that despite what was suggested by the earlier survey results, and in conflict with current management guidelines, there was significant over use of early prophylactic hyperventilation [22]. This result highlights the importance of directly monitoring the applied management, and if it can be achieved in near real-time, will enable future management trials to monitor protocol adherence and better select when patients data can be recruited to a study.

The third and most challenging aim of the BrainIT group is to use its improved infrastructure to generate new evidence on the utility of monitoring and management methods for patients with TBI. The AVERT-IT project, now underway, will put in place in six BrainIT centres, Grid middleware systems enabling direct access to hospital data and remote monitoring of patient management. We believe that this type of remote monitoring facility is a pre-requisite for the conduct of a future multi-centre management trial by the BrainIT group. Discussions of a management trial design have been started at the recent BrainIT group meeting (Vilnius, September 2009) and

the current AVERT-IT project will pilot the feasibility of the remote monitoring infrastructure required for the conduct of such a trial.

## Conclusions

In this study we have shown that it is feasible to collect the BrainIT dataset from multiple centres in an international setting with our IT based methods and the accuracy of the data collected is greater than or equal to 94%, with the exception of the surgery data definition which is being revised. Lessons learned about weaknesses with our data collection methods have been met with advances in client/server tools providing improved validation support. We anticipate that the second generation of BrainIT data collection tools (now being used as part of the current AVERT-IT project) will improve missing data and validation accuracy rates. A future BrainIT management trial will rely on a Grid based infrastructure capable of remotely monitoring patient management and protocol conformance now being piloted in six BrainIT centres. Academic led multi-centre data collection projects must decrease validation costs and to do so will require more direct electronic access to hospital based clinical data sources for both data validation purposes and for reducing the research nurse time needed for double data entry of data currently not accessible from hospital based systems.

## References

- Olesen J, L. M. The burden of brain disease in Europe. *European Journal of Neurology*, 2003, 10, 471-477.
- Bullock R, Chesnut RM, Clifton C, et al. (1996) Guidelines for the management of severe head injury. *J Neurotrauma* 13:643-734.
- Maas AI, Dearden M, Teasdale GM, Braakman R, Cohadon F, Iannotti F, Karimi A, Lapierre F, Murray G, Ohman J, Persson L, Servadei F, Stocchetti N, Unterberg A (1997) EBIC-Guidelines for management of severe head injury in adults. *Acta Neurochir* 139:286-294.
- Ghajar J, Hariri RJ, Narayan RK, Iacono LA, Firlik K, Patterson RH (1995) Survey of critical care management of comatose, head-injured patients in the United States. *Crit Care Med* 23:560-567.
- Jeevaratnam DR, Menon DK (1996) Survey of intensive care of severely head injured patients in the United Kingdom. *BMJ* 312:944-947.
- Matta B, Menon D (1996) Severe head injury in the United Kingdom and Ireland: A survey of practice and implications for management. *Crit care Med* 24:1743-1748.
- Murray GD, Teasdale GM, Braakman R, Cohadon F, Dearden M, Iannotti F, Karimi A, Lapierre F, Maas A, Ohman J, Persson L, Servadei F, Stocchetti N, Trojanowski T, Unterberg A (1999) The European Brain Injury Consortium survey of head injuries. *Acta Neurochir* 141:223-236.
- Stocchetti N, Penny KI, Dearden M, Braakman R, Cohadon F, Iannotti F, Lapierre F, Karimi A, Maas A, Murray GD, Ohman J, Persson L, Servadei F, Teasdale GM, Trojanowski T, Unterberg A, on behalf of the European Brain Injury Consortium (2001) Intensive care management of head-injured patients in Europe: a survey from the European Brain Injury Consortium. *Intensive Care Med* 27:400-406.
- Enblad P, Nilsson P, Chambers I, Citerio G, Fiddes H, Howells T, Kiening K, Ragauskas A, Sahuquillo J, Yau YH, Contant C and Piper I. Survey of traumatic brain injury management in European Brain IT centres year 2001, *Intensive Care Med* (2004) 30:1058-1065.
- Piper I, Citerio C, Chambers I, Enblad P, Nilsson P, Chambers I, Citerio G, Fiddes H, Howells T, Kiening K, Ragauskas A, Sahuquillo J, Yau YH, Contant C. The BrainIT Group: Concept and Core Dataset Definition. *Acta Neurochir* 145:615-629 2003.
- <http://www.kelvinconnect.com/>
- Citerio G, Stocchetti N, Cormio M, Beretta L. Neuro-Link, a computer assisted database for head injury in intensive care. *Acta Neurochir (Wien)*142(7):769-76. 2000
- Zanier E, Ortolano F, Ghisoni L, Colombo A, Losappio S, Stocchetti N. Intracranial pressure monitoring in intensive care: clinical advantages of computerised monitoring over manual recording. *Crit. Care Med.* 11:R7. 2007

14. Corrie J, Piper I, Housely A, Tocher J, Anderson S, Midgley S, Slattery J, Dearden N, Miller J. Microcomputer based data recording improves identification of secondary insults in head injured patients. *British Journal of Intensive Care*, June 1993. 226-233.

15. Venkatesh B, Garrett P, Fraenkel DJ and Purdie D. Indices to quantify changes in intracranial and cerebral perfusion pressure by assessing agreement between hourly and semi-continuous recordings. *Intensive Care Med* 2004; 30: 510-513.

16. Chambers IR, Jones PA, Lo TWM, Forsyth RJ, Fulton B, Andrews PJD, Mendelow AD and Minns RA. Critical thresholds of intracranial pressure and cerebral perfusion pressure related to age in paediatric head injury. *J. Neurol. Neurosurg. Psychiatry* 2006;77;234-240.

17.[17] Signorini DF, Andrews PJD, Jones PA, Wardlaw JM and Miller JD. Adding insult to injury: the prognostic value of early secondary insults for survival after traumatic brain injury. *J. Neurol. Neurosurg. Psychiatry* 1999;66;26-31

18.[18] <http://www.avert-it.org>

19.[19] <http://www.nesc.ac.uk>

20.[20] <http://www.brainit.org/bit2web/faces/Papers.jsp>

21.[21]

<http://www.brainit.org/bit2web/faces/Meetings.jsp>

22.[22] Neuman J, Chambers I, Citerio G, Enblad P, Gregson B, Howells T, Mattern J, Nilsson P, Piper I, Ragauskas A, Sahuquillo J, Yau H, Kiening K on Behalf of the BrainIT Group. The use of hyperventilation therapy after Brain Injury in Europe: An analysis of the BrainIT database. *Intensive Care Medicine* 2008; S00134-008-1123-7.

23.[23] <http://www.nesc.ac.uk/hub/projects/votes/>

### Acknowledgements

We wish to acknowledge the contribution of all data contributing members of the BrainIT group ([www.brainit.org](http://www.brainit.org)) who supported the EEC project: QLGC-2002-01160.

Investigators and Participating Centres  
 Barcelona Spain, Prof J Sahuquillo;  
 Cambridge UK., Prof JD Pickard;  
 Edinburgh UK, Prof R Mins, Prof I Whittle; Glasgow UK, Mr L Dunn;  
 Gothenburg Sweden, Dr B Rydenhag;  
 Heidelberg, Germany, Dr K Kiening; Iasi Romania, Dr St.M. Iencean; Kaunas Lithuania, Prof D Pavalkis; Leipzig Germany, Prof J Meixensberger; Leuven Belgium, Prof J Goffin; Mannheim Germany, Prof P Vajkoczy; Milano Italy, Prof N Stocchetti; Monza Italy, Dr G

Citerio; Newcastle upon Tyne UK, Dr IR Chambers; Novara Italy, Prof F Della Corte; Southampton UK, Dr J Hell; Uppsala Sweden, Prof P Enblad; Torino Italy, Dr L Mascia; Vilnius Lithuania, Prof E Jarzemaskas; Zurich Switzerland, Prof R Stocker

### Corresponding Author:

Ian Piper  
 Brain-IT Group Coordinator  
 Intensive Care Monitoring  
 Dept. Clinical Physics, 5th Floor  
 Institute of Neurological Sciences  
 Southern General Hospital  
 1345 Govan Road, Glasgow, UK,  
 G514TF  
 Tel: +44(0)141-201-2595  
 Fax: +44(0)141-201-2592  
 Email: [ipiper@clinmed.gla.ac.uk](mailto:ipiper@clinmed.gla.ac.uk)

**Table 1**  
**Demographic and Clinical Features of Feasibility Study Data set (n = 199)**

Sex			TCDB (Worst)		
	<i>Male</i>	162		<i>Diffuse1</i>	9
	<i>Female</i>	37		<i>Diffuse2</i>	51
Age				<i>Diffuse3</i>	34
	<i>Mean</i>	36.1		<i>Diffuse4</i>	12
	<i>Range</i>	4-83		<i>Mass</i>	60
	<i>&lt;14yo</i>	7		<i>Missing</i>	33
Trauma Type			GOSe		
	<i>RTA</i>	84		<i>1 (Dead)</i>	31
	<i>Pedestrian</i>	16		<i>2</i>	3
	<i>Fall</i>	55		<i>3</i>	35
	<i>Assault</i>	18		<i>4</i>	8
	<i>Sport</i>	6		<i>5</i>	30
	<i>Work</i>	5		<i>6</i>	17
	<i>Missing</i>	14		<i>7</i>	30
				<i>8</i>	24
				<i>Missing</i>	21

**Table 2**  
**Summary of Data Collected**

Data Type	No. of Fields	Avg No. of Rows per Patient
Demographic ( <i>eg: PNSH/NSH</i> )	109	1
ICU_Monitoring ( <i>eg: Types of Device/Location...</i> )	12	15.0
Neurological Status ( <i>eg: GCS/Pupils</i> )	10	42.3
Other_Clinical_Events ( <i>eg: Blood Samples, Suction...</i> )	20	230.9
Surgery	11	1.4
Target_Therapies	59	69.6
Daily_Observations ( <i>eg: Daily Summaries of Management</i> )	11	8.4
<b>Total</b>	<b>232</b>	



**Table 3**  
**Monitoring Data Distribution**

<b>Channel</b>	<b>Number of Patients</b>
BP (blood pressure: mmHg;systolic, diastolic, mean)	199
ICP (intracranial pressure: mmHg;mean)	195
CPP (cerebral perfusion pressure: mmHg;mean)	195
HRT (Heart Rate: bpm)	165
SaO2 (arterial Oxygen saturation: %;pulse oximetry)	164
Tc (core temperature: degrees C)	149
CVP (central venous pressure: mmHg; mean)	105
ETCO2 (end tidal CO2: mmHg)	79
NIBP (blood pressure: mmHg;systolic, diastolic, mean)	50
Tp (peripheral temperature: degrees C)	17
PtiO2 (brain tissue oxygen partial pressure: mmHg)	11
SjO2 (jugular venous oxygen saturation: %)	10
CO (cardiac output: ml/hour)	7
brTemp (brain temperature: degrees C)	3
PrX (bp-icp reactivity:dimensionless)	1

**Table 4**  
**Therapy Type Vs Missing “End Times”**

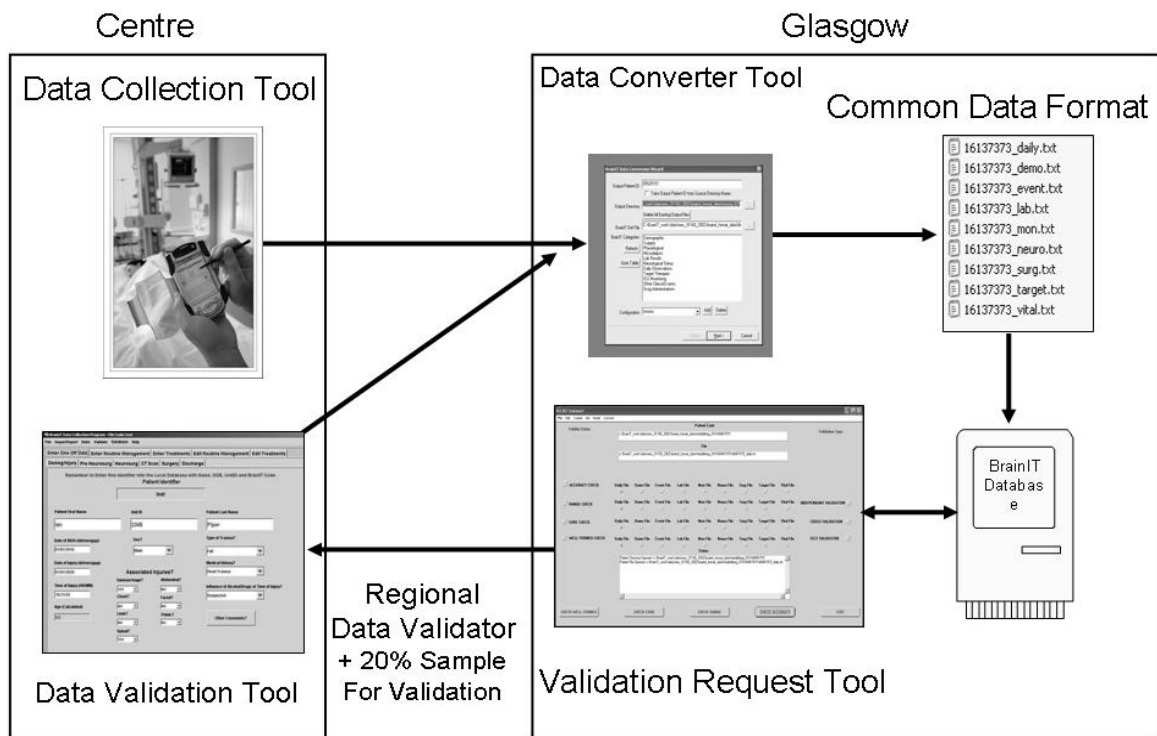
<b>Therapy</b>	<b>Start Entries</b>	<b>End Entries</b>	<b>Missing End Entries</b>
Sedation	1108	499	55%
Analgesia	1032	574	44%
Paralysis	741	460	38%
Volume Expansion	1674	1308	12%
Inotropes	614	199	68%
Anti-Hypertensives	63	22	65%
Anti-Pyretics	788	505	36%
Hypothermia	22	10	55%
Steroids	51	6	88%
Cerebral Vasoconstr.	0	0	---
Osmotics (Mannitol)	807	538	33%
Barbiturates	90	45	50%
Other	2576	2026	21%
<b>Totals</b>	<b>9566</b>	<b>6192</b>	<b>35%</b>

**Table 5**  
**Percentage Error Rate by Data Type Class with Description of Common Error Types.**

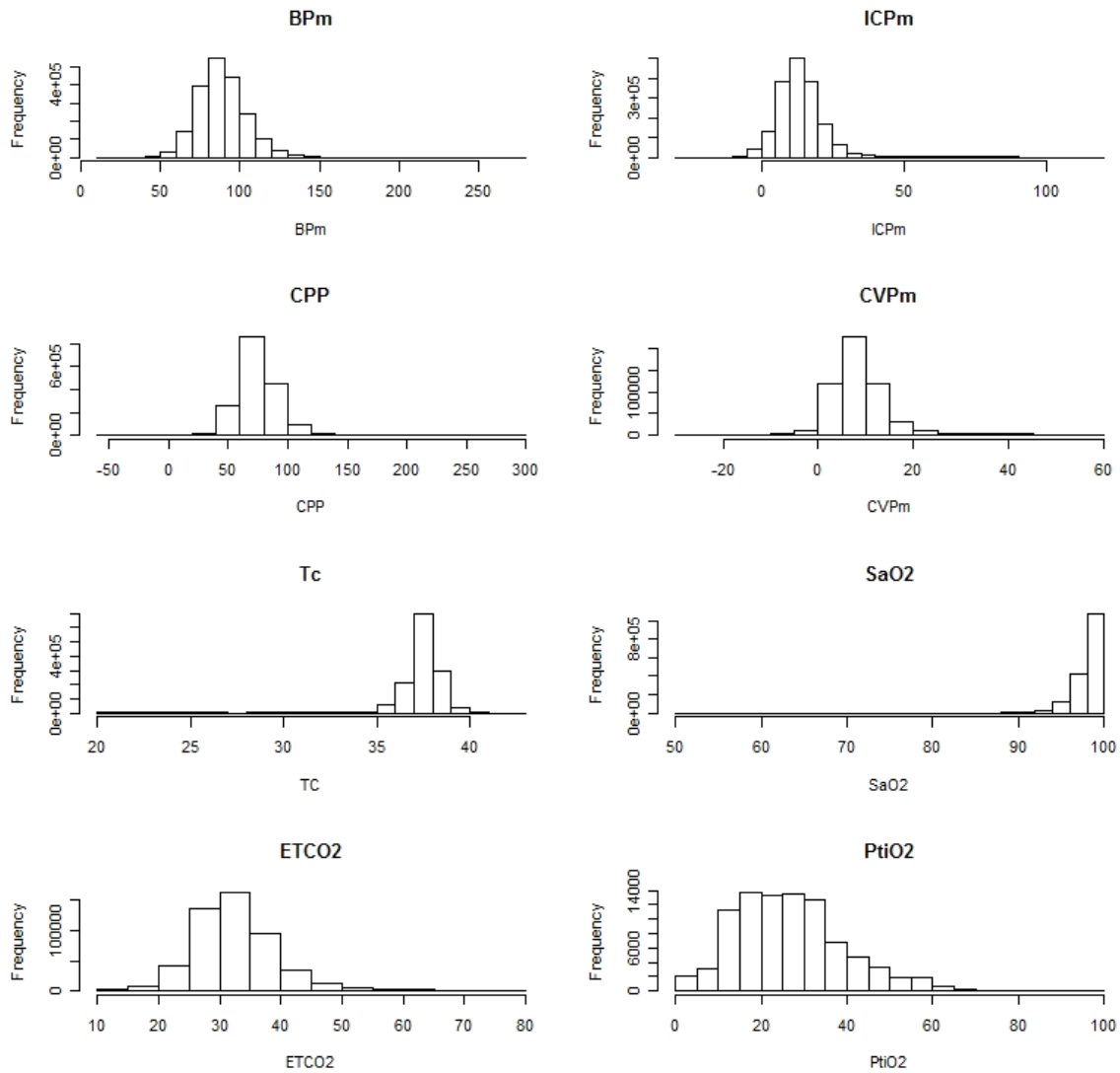
<b>Data Class</b>	<b>Error Rate (%)</b>	<b>Common Fields with Errors</b>
<i>Laboratory</i>	2	pCO <sub>2</sub> , FiO <sub>2</sub> value wrong
<i>Demographic</i>	4	Monitoring time on arrival at neurosurgery, intubation present on arrival at neurosurgery wrong
<i>Neuro Observations</i>	5	Pupil Size, GCSv (code 1 Vs Unknown code error)
<i>Monitoring Summary</i>	5	ICP type, ICP Location wrong
<i>Daily Management Summary</i>	5	Infusion type (bolus Vs infusion or both), drug number (1 or > 1)
<i>Targeted Therapy</i>	6	Non-standard target, no Target specified
<i>Surgeries</i>	34	ICP placement, Skull #, mass lesion wrong

**Table 6**  
**Monitoring Data Validation Results – Bias (+- 95% CL) Between Nurses Chart Recorded Values Vs Computer Collected End Hour Averages**

Value	Data Type				
	ICP (mmHg)	BP (mmHg)	CPP (mmHg)	SaO2 (%)	Tc (C)
Bias	-0.15	0.16	0.46	0.46	-0.29
+95%	0.32	1.57	1.81	1.23	0.09
-95%	-0.62	-1.25	-0.88	-0.31	-0.67
n	749	558	457	499	223



**Figure 1** Graphical representation of the data validation process. Centre staff enter data using client side tools such as the hand held PDA. Data is uploaded via the BrainIT web-services and a server-side convertor converts data into the series of common data format files which are input into the BrainIT SQL database. A validation request tool residing on the database server randomly samples 20% of the data uploaded for each data category and generates a validation request file listing the timestamps and data items to be checked by local data validators. Data validators move between their designated centres and enter into a data validation tool the requested data items from source documentation held in each local centre. The resulting validation data file is uploaded to the BrainIT data coordinating centre via the website and using data validation checking software tools, the validated data is checked against the data items originally sent from which percentage accuracy data is calculated



**Figure 2 is a histogram plot showing the quantity and spread of time-series data for the main monitored channels: ICP, BP, CPP, CVP, SaO2, Core Temperature, ETCO2 and PtiO2. The number of data points sampled per channel ranges from 89,524 for PtiO2 to 1.98 million samples for BPm. (BPm = 1,979,284, ICPm = 1,748,423, CPP = 1,719,166, CVPm = 541,524, SaO2 = 1,656,614, Tc = 1,372,641, ETCO2 = 502,524, PtiO2 = 89,524**

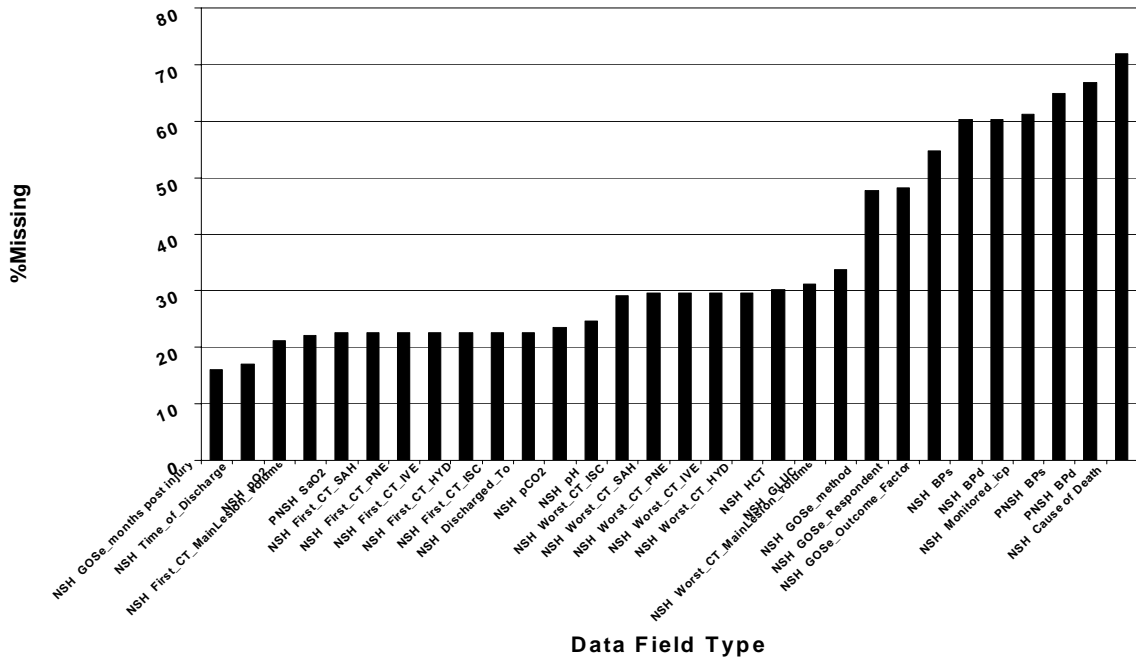


Figure 3 Graph showing “One-Off” demographic and clinical data fields with greater than 15% of missing data

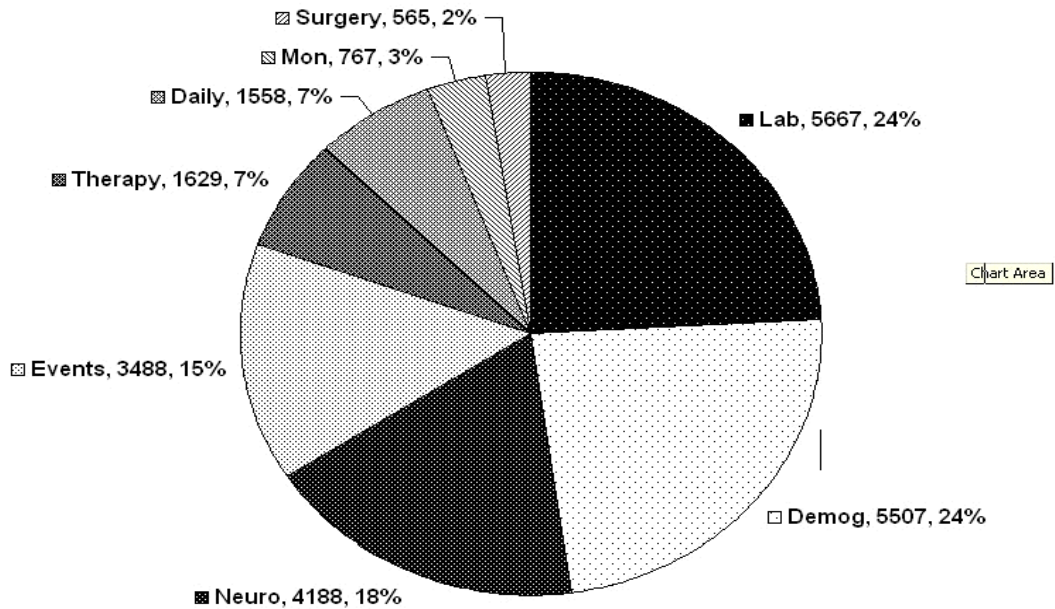


Figure 4 Pie chart showing the distribution of the 19,461 data validation comparisons which were made in proportion to the size of the data received with the largest number checked in laboratory data (5,667) and the least in the surgery data (567)

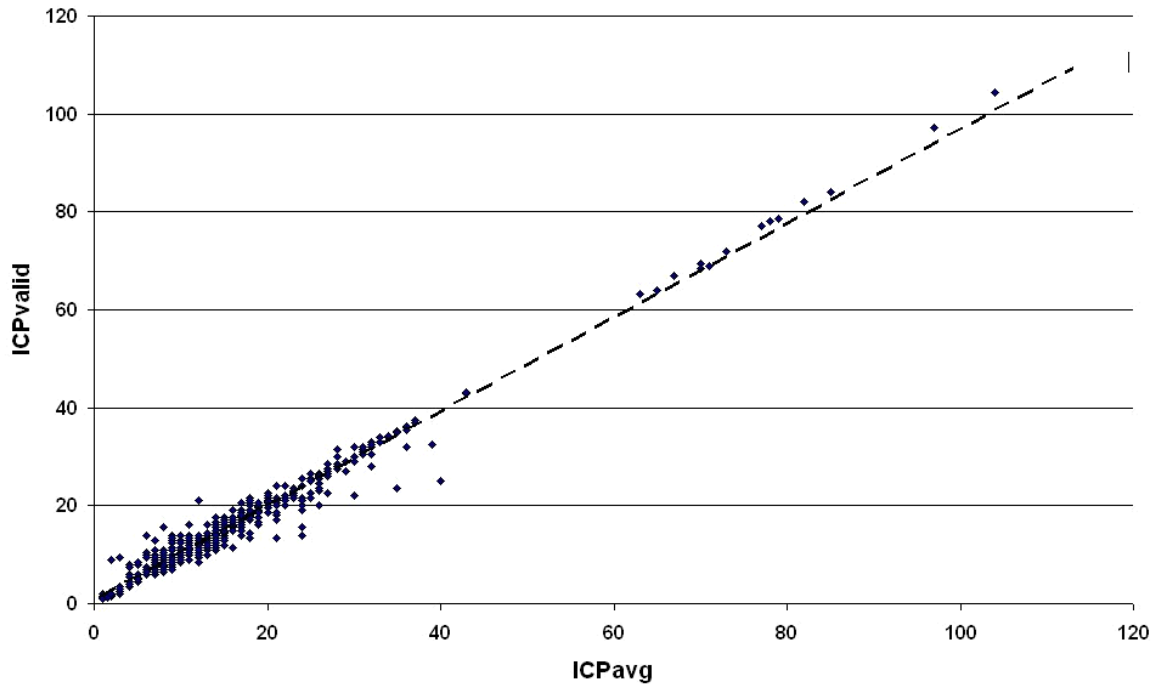


Figure 5 Scatter plot of computer monitored minute by minute ICP data from an example patient showing the data averaged over 60 minutes (ICPavg) plotted against nurses chart end hour values (ICPvalid). Linear regression best fit R2 value = 0.9773

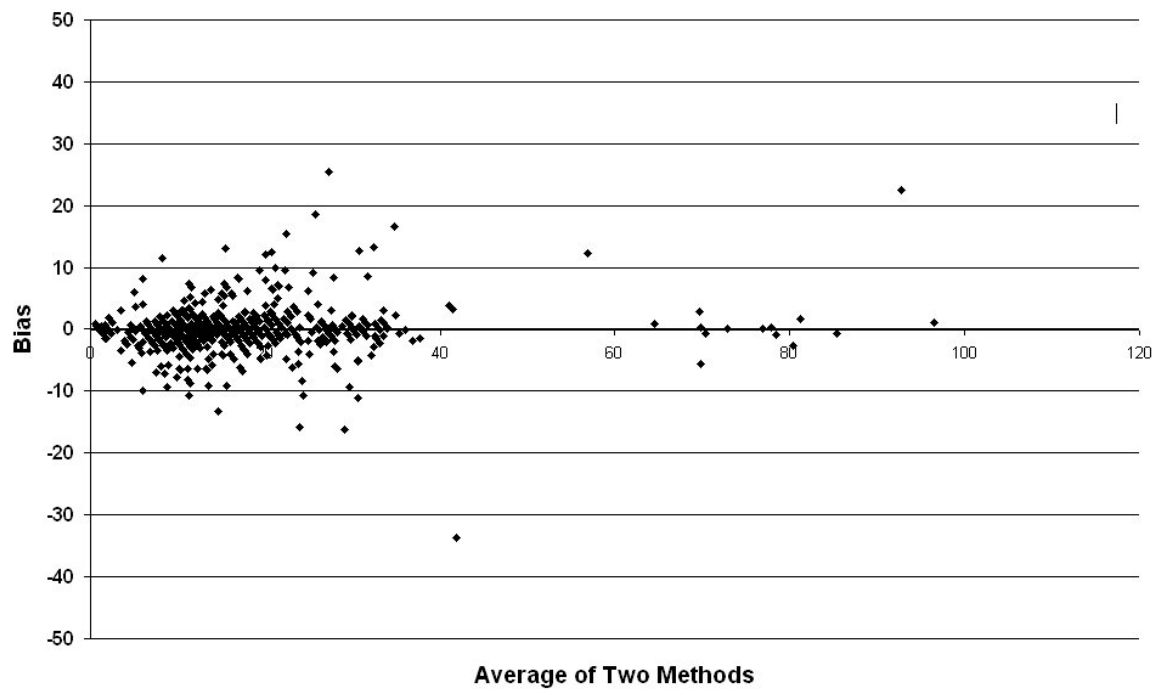


Figure 6 Altman and Bland plot from an example patient showing the average bias (-0.15 mmHg) and 95% confidence limits (0.12, -0.45) for the computer monitored end hour averaged data Vs the nurses chart end hourly recorded values collected by the validation nurses