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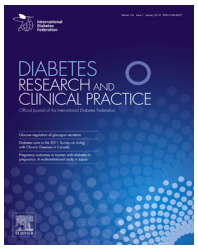

Trends in recorded capillary blood glucose and hypoglycaemia in hospitalised patients with diabetes

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ABSTRACT

Aims: To utilise whole-system analysis of capillary glucose measurement results to examine trends in timing of glucose monitoring, and to investigate whether these timings are appropriate based on observed patterns of hypoglycaemia.

Methods: Near-patient capillary blood glucose results from eight acute hospitals collected over 57 months were analysed. Analysis of frequency of measurement, and measurements in the hypoglycaemic (<4 mmol/l) and severe hypoglycaemic (<2.5 mol/l) range per time of day was made.

Results: 3 345 241 capillary glucose measurements were analysed. 1 657 594 capillary blood glucose values were associated with 106 624 admissions in those categorised as having diabetes. Large peaks in frequency of glucose measurements occurred before meals, with the highest frequency of capillary glucose measurement activity being seen pre-breakfast. Overnight, an increase in measurement activity was seen each hour. This pattern was mirrored by frequency of measured hypoglycaemia. 27 968 admissions (26.2%) were associated with at least one hypoglycaemic measurement. A greater proportion of measurements were within the hypoglycaemic range overnight with 61.7% of all hypoglycaemia between 2100 and 0900 h, with peak risk of measured capillary glucose being hypoglycaemic between 0300 and 0400 h.

Conclusions: Hypoglycaemic is common with the greatest risk of hypoglycaemia overnight and a peak percentage of all readings taken being in the hypoglycaemic range between 0300 and 0400 h. Measurement activity overnight was driven by routine, with patterns of proportion of measurements in the hypoglycaemic range indicating that there may be a significant burden of undiscovered hypoglycaemia in the patients not routinely checked overnight.

1. Introduction

Capillary blood glucose monitoring is performed routinely in hospital to manage patients at risk of hyperglycaemia and hypoglycaemia and point of care capillary blood glucose measurement can be considered as analogous to an additional "vital sign" for hospitalised patients with diabetes.

Diabetes is common amongst hospital inpatients in the United Kingdom, Europe and North America being thought to be present in between 1 in 5 and 1 in 10 hospital stays [1–3].

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Diabetes has been unequivocally shown to negatively impact both mortality and length of stay in hospital in a variety of medical and surgical settings prompting an increasing focus on improving inpatient glycaemic control [2,4–7].

In hospitalised patients with diabetes, hypoglycaemia is common, and in patients both with and without diabetes its frequency and severity has been associated with an increase in pre and post discharge mortality and length of stay [8–10].

The ACE/ADA Task Force on Inpatient Diabetes in 2006 stressed the importance of glycaemic control and raised concerns regarding under and over treatment of glycaemia citing insufficient frequency of glucose monitoring as a potential safety issue [11]. The 2013 ADA standards of medical care for patients with diabetes suggest glucose monitoring in all people with, and at risk of, diabetes citing the importance of glycaemic control and hypoglycaemia avoidance. Guidance on frequency of glucose monitoring by point of care testing is only given for patients treated with insulin with between 4 and 6 hourly to ½ hourly to 2 hourly for those on intravenous insulin suggested [12]. In the UK the National Diabetes Inpatient Audit has recommended that glucose is checked weekly for stable diet controlled patients and 4 times a day for unwell patients, unstable diabetes or those treated by basal bolus insulin therapy [13].

The Greater Glasgow and Clyde Health Board in Scotland performs around 700 000 near patient capillary blood glucose tests per year. The purpose of this study is to utilise whole system analysis of these results to examine current trends in timing of monitoring and assess if these timings are appropriate based on observed patterns of hypoglycaemia.

2. Materials and methods

Capillary blood glucose data were extracted from the Abbott Precision Webb system [Abbott, UK]. Whole-hospital data were included from eight acute hospitals and associated units within Greater Glasgow and Clyde Health Board (Gartnavel General Hospital, Western Infirmary, Glasgow Royal Infirmary, Victoria Infirmary, Southern General Hospital, Royal Alexandria Hospital, Inverclyde Hospital and Vale of Leven Hospital) between dates 01/01/2008 and 01/05/2013. Data collected from intensive care environments were excluded as it was felt likely that the capillary glucose monitoring in these areas would be very different from general medical and surgical wards. Data available from the system included patient identifier, patient location, test date and time and capillary glucose value.

All data manipulation and analysis was performed using bespoke code written in statistical language R [14].

Prior to analysis of the complete data set it became apparent that a number of capillary blood glucose measurement values were not attributable to an identifiable patient and were removed.

We wished to limit our analysis as much as possible to data from patients with diabetes and we were aware that a proportion of capillary blood glucose measurements are performed as a routine admission test in people without diabetes. Based on the World Health Organisation diagnostic criteria for diabetes we assumed that either morning (between 0500 and 0700 h) capillary blood glucose of $\geq$7 mmol/l or 2 random capillary blood glucose of $\geq$11.1 mmol/l indicated diabetes. This was felt to give the best possible dataset for further analysis, consisting of subjects likely to have diabetes without unduly excluding individuals with diabetes from analysis.

Dates of admission and discharge from hospital were implied following examination of the comparison with case note review dataset. Any gap of five or more days between capillary blood glucose measurements was taken as the threshold for determining a new admission episode.

Analysis of frequency of glucose measurement per time of day was made. A similar frequency analysis was made of hypoglycaemic measurements ($<$4 mmol/l), and severe hypoglycaemic capillary glucose measurements ($<$2.5 mmol/l). We used the National Health Service Diabetes guideline treatment cut-off value (blood glucose values $<$4 mmol/l) to categorise hypoglycaemia. Severe hypoglycaemia is best categorised by the need for third-party assistance in treating the episode. As this information was not available to us a value of $<$2.5 mmol/l was used to describe severe hypoglycaemia [15]. Comparison was made between the frequency of hypoglycaemic measurements during daytime (0900–2100) and night time (2100–0900) hours.

The number of capillary glucose measurement in the hypoglycaemic range ($<$4 mmol/l) as a proportion of all capillary glucose measurements was calculated for the dataset as a whole and for each hour of the day.

We observed peaks and troughs of glucose measurement activity overnight with peaks occurring at 0100, 0200, 0300, and 0400 h. We calculated the proportion of capillary blood glucose measurements in the hypoglycaemic range for a 30 min window centred on these peaks in activity, and also in the corresponding 30 min activity troughs bordering the peaks. We repeated the analysis of the four peaks in measurement activity at 0100, 0200, 0300 and 0400 h excluding any measured capillary blood glucose occurring within 1 h of any initial measurement $<$4 mmol/l.

3. Results

The initial raw dataset consisted of 3 345 241 capillary glucose measurements. 1 836 258 capillary glucose values were associated with 60 256 valid patient identifiers, corresponding to 172 771 admission episodes over 57 months of data acquisition. 1 657 594 capillary blood glucose values were associated with 106 624 admissions during which a diagnosis of diabetes was made using glycaemic parameters. The remainder of the discussion will consider those subjects in whom a glycaemic diagnosis of diabetes was made.

4. Timing of capillary blood glucose measurements

Increases in measurement activity were identified with large peaks in frequency of capillary blood glucose measurements at pre-meal times. The highest frequency of capillary blood glucose measurement activity was seen pre-breakfast, with less pronounced peaks identified before lunchtime and