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Glucose alert system improves health professional responses to adverse glycaemia and reduces the number of hyperglycaemic episodes in non-critical care inpatients

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- Lack of health professional response (clinical inertia) to adverse glycaemia is a major barrier to improving diabetes care in the hospital setting.
- To improve health professional responses, a novel glucose alert system comprising the Melbourne Glucose Alert Pathway (a clinical escalation and management guide) and glucose alert-capable networked blood glucose meters was implemented and evaluated.
- The glucose alert system improved health professional responses and decreased the number of hyperglycaemic episodes and could be a component of various strategies in improving the care of hospitalized people with diabetes.

Abstract

Aim To investigate the effect of a novel glucose alert system, comprising the Melbourne Glucose Alert Pathway and glucose-alert-capable networked blood glucose meters, on nursing and hospital medical officer responses to adverse glycaemia.

Methods A prospective, pre- and post-observational study was undertaken in non-critical care wards of a tertiary hospital over 4 months (*n*=148 or 660 patient-days). The intervention consisted of two components designed to promote a consistent staff response to blood glucose measurements: (1) a clinical escalation pathway, the Melbourne Glucose Alert Pathway, and (2) networked blood glucose meters, which provide a visual alert for out-of-range blood glucose measurement. All consecutive inpatients with diabetes were assessed for diabetes management and capillary blood glucose. The primary outcome was documented nursing and medical staff action in response to episodes of adverse glycaemia (blood glucose >15 mmol/l or <4 mmol/l). Secondary outcomes consisted of glycaemic measures.

Results In response to adverse glycaemia, nursing action increased (proportion of nursing staff taking action: 45% to 73%; *P*<0.001), and medical action increased (proportion of medical officers taking action: 49% to 67%; *P*=0.011) with the glucose alert system in place. Patient-days with hyperglycaemia (any blood glucose value >15 mmol/l: 24% vs 16%; *P*=0.012) and patient-days with mean blood glucose >15 mmol/l (7.4% vs 2.6%; *P*=0.005) decreased. There was no difference in hypoglycaemia rates.

Conclusions Use of a novel glucose alert system improved health professional responses to adverse glycaemia and decreased hyperglycaemia in the hospital setting.

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Introduction

In hospitalized individuals, both hyper- and hypoglycaemia are associated with worse outcomes [1–4]. The term 'adverse glycaemia' can be used to describe both extremes of hyperglycaemia and hypoglycaemia, which should be avoided. Despite established glycaemic targets in the non-critical care setting [5,6], glycaemic control remains suboptimal with hyperglycaemia occurring in up to 80% of inpatient diabetes admissions [7,8], and hypoglycaemia occurring in 20% of admissions [7,9].

Clinical inertia in acute diabetes care can be defined as a lack of health professional action in response to adverse glycaemia and is a significant barrier to optimizing glycaemia in hospital. Despite hyperglycaemia being common in diabetes inpatients, capillary blood glucose (BG) measurements are often overlooked and appropriate intensification of therapy does not occur [10]. Persistent hyperglycaemia or recurrent hypoglycaemia on multiple consecutive days may occur without appropriate adjustment in therapy [11]. Clinical inertia is evident in both nursing and hospital medical officer practice. Nursing staff who perform point-of-care BG observations may not escalate a case to medical staff for assistance with managing out-of-range BG measurements, and hospital medical officers may not review BG observation charts daily, make appropriate therapy adjustment, or refer to specialist diabetes services for assistance.

Glucose alert systems have been shown to improve staff action in response to adverse glycaemia. In the intensive care setting, real-time computer-generated glucose alert systems (which provide audio-visual alerts when BG measurements are out of range) have been used to facilitate insulin infusion adjustment by the treating nurse, and can improve glucose control [12,13]. In the non-critical care setting, structured glucose observation charts (with a coloured background to indicate when BG measurements are out of range), accompanied by hyperglycaemia and hypoglycaemia management guidelines have been used to encourage staff response to adverse glycaemia [14]. The efficacy of this approach to address clinical inertia has not been studied in detail, although one study observed a decrease in hyperglycaemia after the introduction of a structured BG observation chart [15].

Networked BG meters are point-of-care devices that link BG measurements to patient identifiers and store this information in a central database. Hospital-wide implementation of

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networked BG meters enables collection of electronic point-of-care BG data for research, quality improvement and benchmarking of glycaemic control between hospitals [16,17]. In addition, networked BG meters can be programmed to display visual cues when BG measurements are outside a predefined range and therefore could function as an alert device for adverse glycaemia.

Experts have suggested that system-based solutions are required to overcome obstacles for glycaemic control in hospital [18]. In an attempt to decrease clinical inertia and improve glycaemic control, we developed a glucose alert system designed to escalate health professional responses to adverse glycaemia. The glucose alert system comprised the Melbourne Glucose Alert Pathway (GAP), along with glucose-alert-capable networked BG meters. We hypothesized that this glucose alert system would increase nursing and hospital medical officer responses to adverse glycaemia.

Methods

This was a prospective observational study conducted over a 4-month period in 2015. It was performed on two wards at the Royal Melbourne Hospital, a tertiary teaching hospital affiliated with the University of Melbourne, and approved by the local Human Research Ethics Committee.

Population

Consecutive inpatients with diabetes who were admitted to one of two study wards were recruited. One surgical ward (predominantly vascular and urology surgery) and one medical ward (predominantly general medicine) were included in the present study because of the relatively high prevalence of diabetes in these wards. We excluded people with hyperglycaemia without a history of diabetes, and those admitted under endocrinology or palliative care units, or admitted for <1 day. Participant information, capillary BG measurements and diabetes management during hospitalization were collected prospectively from progress notes and bedside charts. For people with a prolonged hospital stay, only the first 14 days of admission were collected and analysed.

Baseline: routine care

At our hospital, diabetes management is primarily the responsibility of the hospital medical officers of the admitting unit. The specialist diabetes referral team (diabetes nurse and

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endocrinologist) is available for assistance on a formal referral basis. Documentation and management of acute inpatient care is performed via written medication orders, glucose observation charts and progress notes at the bedside. In accordance with local practices, there is no standardized algorithm of routinely withholding all antidiabetic medications and commencing regular and/or supplemental subcutaneous insulin on all patients admitted to hospital. A hypoglycaemia management algorithm has been in routine use, but a hyperglycaemia management algorithm has not been used.

During the baseline period, there was no formal glucose-based alert system and non-networked (and not alert-capable) point-of-care capillary BG meters (Freestyle optium®; Abbott Diabetes, Alameda, CA, USA) were in use. Baseline 2-month data collection was performed prior to implementation of the glucose alert system.

Intervention

The glucose alert system consisted of two components: (1) the GAP and (2) glucose-alert-capable networked BG meters.

The first component, the GAP, was a structured clinical escalation pathway to be used by nursing and medical staff in response to BG measurements (Fig. 1). The GAP was developed by a multidisciplinary team of nursing and medical staff in conjunction with the Department of Diabetes and Endocrinology at the Royal Melbourne Hospital. The GAP is a colour-coded guide attached to the bedside glucose observation charts consisting of four different BG ranges with corresponding action responses for nursing and medical staff. The four BG ranges are hypoglycaemia (BG <4.0 mmol/l, red), safe glycaemia (BG 4.0–10.0 mmol/l, green), acute hyperglycaemia (one BG 15.1–20.0 mmol/l or two consecutive BG 10.1–15.0 mmol/l, yellow) or critical hyperglycaemia (BG >20.0 mmol/l, red). Within each range, recommended nursing actions are summarized as follows: manage the situation, monitor BG more intensively and notify medical officer. The recommended medical officer actions are summarized as follows: review BG, revise diabetes treatment and refer to diabetes team for assistance. In addition to glucose measurements, the GAP also provided recommendations in response to clinical changes that may affect BG (such as fasting, provision of enteral nutrition, or glucocorticoid treatment).

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The second component was the glucose-alert-capable networked BG meters, which enabled a visual alert for out-of-range BG measurements and facilitated electronic transfer and storage of BG data linked to a unique identifier. Two networked BG meter systems [Nova Statstrip® (Australasian Medical and Scientific Ltd, Chatswood, NSW, Australia) and Freestyle Precision Pro® (Abbott Diabetes)] were introduced to our hospital and used in the present study. Networked BG meters were programmed to display visual alerts when BG was outside the optimal range defined in the GAP. The visual alerts consisted of a yellow highlight or single arrow for moderately out-of-range measurements (BG 3.1–3.9 mmol/l or 10.1–20.0 mmol/l) and a red highlight or double arrows for critically out-of-range measurements (BG <3.0 mmol/l or >20.0 mmol/l). Nursing staff continued to record BG measurements manually on the bedside glucose observation charts, as per routine clinical care.

All nursing staff and medical officers underwent group education sessions on both components of the glucose alert system. A 2-month intervention period and data collection was undertaken with the glucose alert system in place.

Outcomes

The primary outcome was staff response to adverse glycaemia. An episode of adverse glycaemia was defined as a patient-day with capillary BG in the severe hyperglycaemia range (BG >15 mmol/l) or hypoglycaemia range (BG <4 mmol/l). These thresholds were chosen because severe hyperglycaemia is associated with adverse physiology (neutrophil dysfunction, osmotic diuresis) [19] and hypoglycaemia <4 mmol/l is associated with counter-regulatory hormone responses and adverse events [20]. Adverse glycaemia indicated unsafe glycaemic extremes that should be avoided and should prompt a review of diabetes management and adjustment of therapy [9].

Nursing and medical staff responses (<24 hours after an episode of adverse glycaemia) were assessed. Nursing response was defined as documented evidence of notifying (or escalating to) medical officers about adverse glycaemia. Medical officer response was defined as documented evidence of one or more of the following: reviewing BG observations; revising diabetes treatment (adjustment of diabetes medication or insulin, including prescription of correctional dose of insulin, as per the medication prescription chart); or escalating by referral to the specialist diabetes team. To account for potential confounders that may affect staff

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action, a logistic regression analysis was also performed to evaluate staff response to hyperglycaemia, adjusting for the peak BG (severity of hyperglycaemia), insulin treatment, admission unit and day of occurrence (weekday vs weekend).

Secondary outcomes were measures of glycaemic control (patient-days with hyperglycaemia or hypoglycaemia and patient-day mean glucose). To ensure BG measurement assessment was consistent across the entire study, capillary BG measurements that were documented in writing by the nursing staff in the BG observation charts were used, rather than electronically extracting data from networked BG meters. In addition, we excluded repeated BG measurements from a single episode of hypo- or hyperglycaemia as previously described [21]. Despite differences in chemical methods, all the BG meters in the study comply with the 2013 ISO: 15197:2013 standards and therefore we anticipated minimal difference in BG measurements in this non-critically ill population. Outcomes were compared between the baseline and intervention periods using Fisher's exact test, a *t*-test or a rank-sum test, as appropriate, using Minitab® version 17.2.1 (Minitab Inc., State College, PA, USA). At the conclusion of the study, nursing staff were asked to complete a survey evaluating satisfaction with both components of the glucose alert system.

Results

In the present study, we observed a total of 148 inpatients (660 patient-days), including 70 persons (349 patient-days) in the baseline period and 78 inpatients (311 patient-days) in the intervention period. The groups were well matched between baseline and intervention periods (Table 1). The majority had Type 2 diabetes, a third were receiving insulin treatment prior to admission and the mean HbA_{1c} was 57 mmol/mol (7.4%). This cohort consisted of largely surgical admissions (80%), with half admitted for elective procedures. The median length of stay was 4 days per person.

During the study there were 168 episodes of adverse glycaemia, with severe hyperglycaemia (>15 mmol/l) and hypoglycaemia (<4 mmol/l) occurring in 24% and 7% of patient-days, respectively. In the baseline period there were 101 episodes of adverse glycaemia compared with 67 episodes in the intervention period. In response to adverse glycaemia, nursing responses increased from 45% during the baseline period to 73% during the intervention period ($P<0.001$). Medical responses increased from 49% during the baseline period to 67% during the intervention periods ($P=0.011$). The medical responses consisted mostly of

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reviewing BG measurements and revision of diabetes treatment (Table 2). After multivariable adjustment, staff response to hyperglycaemia was much more likely during the intervention than the baseline period [nursing action: adjusted odds ratio 6.7 (95% CI 2.5, 18.1); medical action 4.9 (95% CI 1.9, 12.7); Appendix S1].

On glucometric analyses, 1331 and 1077 BG measurements were observed in the baseline and intervention periods, respectively. Frequency of BG monitoring was as per local guidelines (median 4 measurements per person-day) and was consistent throughout the entire study. Patient-days with severe hyperglycaemia (>15 mmol/l) decreased (24% vs 16%; *P*=0.012), and patient-days with critical hyperglycaemia (>20 mmol/l) decreased (9% vs 2%; *P*<0.001). Patient-days with mean BG >15 mmol/l decreased [7.4% vs 2.6%; *P*=0.005 (Fig. 2)]. There was no difference in patient-days with hypoglycaemia (BG <4 mmol/l; 7% vs 6%; *P*=0.9) or severe hypoglycaemia (BG <3mmol/l; 3.4% vs 2.8%; *P*=0.8). The proportion of patients with severe hypoglycaemia during hospitalization was not different (11% vs 5%; *P*=0.2). Patient-day mean glucose was not different (although showed a trend to decrease) between baseline and intervention periods (9.5±3.2 vs 9.1±2.5 mmol/l; *P*=0.082).

Satisfaction surveys were returned by 24 nurses (40% of eligible nurses). Twenty respondents (83%) were satisfied with the GAP, and 18 respondents (75%) were satisfied with networked BG meters; however, 25% indicated that the alert system placed increased demands on their time. The majority responded that both components improved patient safety (Appendix S2).

Discussion

In keeping with previous literature, the present study identified frequent episodes of adverse glycaemia in non-critical care inpatients with diabetes. In the baseline period of this study, more than half of adverse glycaemic episodes did not lead to documented action by nursing or medical staff, highlighting significant clinical inertia. Adjustment of diabetes treatment occurred in only one-third of episodes, similar to findings in a previous study in which only 22% of patient-days with hyperglycaemia led to treatment intensification [22].

Intervention with an instructive visual glucose alert system aiming to escalate health professional responses resulted in significant improvement in responses to adverse glycaemia. Increased staff responses were most evident in nursing staff, where a 62%

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increase in notification of adverse glycaemia to hospital medical officers was observed. Similarly, medical staff reviewed BG measurements and made adjustment to diabetes treatment more often. The two components of the glucose alert system were designed to work in concert, as networked BG meters provided a visual alert for an out-of-range BG measurement, prompting staff to refer to the GAP, which then provided the clinical escalation and management guideline. In addition, treating staff were aware that patient-identifiable BG data were electronically recorded with the theoretical potential for remote electronic surveillance (which was not performed in this study), which may have encouraged a greater sense of accountability for BG management. Improved accountability is an important aspect of improving inpatient diabetes management, which can be facilitated by networked BG meters [23]. In the present study it was not possible to determine the relative contributions of the two components to modification of staff action.

Increase in the proportion of staff who took action also resulted in significant improvements in glycaemia, with a 33% decrease in episodes of hyperglycaemia (BG >15 mmol/l), and a 65% decrease in patient-days with mean glucose levels >15 mmol/l was observed. Other studies have shown similar improvements in glycaemic control using alternative glucose alert interventions aimed at increasing staff responses. Roman *et al*. [15] devised a colour-coded BG monitoring chart that provided visual alerts for out-of-range BG trends, coupled with a management algorithm. This intervention resulted in a 41% decrease in the frequency of prolonged hyperglycaemia (three consecutive BG measurements >13.9 mmol/l) [15]. Donihi *et al*. [24] studied a glycaemic management team who remotely monitored BG measurements and alerted treating teams of the occurrence of severe hyperglycaemia (BG >16.7 mmol/l). This approach improved treating team staff response by 50%, and decreased the occurrence of subsequent severe hyperglycaemia by 55% [24]. Our study supports the evidence that increasing health professional action (and decreasing clinical inertia) in response to adverse glycaemia may improve glycaemic control in hospital.

Glucose alert systems in the non-critical care setting can vary greatly in function and complexity, as evident in a relatively small number of heterogeneous studies [15,24–28]. A manual alert system may be a simple colour-coded BG monitoring chart, whilst an electronic alert system uses point-of-care BG data and generates computerized alerts when predefined BG criteria are met. An alert may be generated electively by a user (e.g. when the user logs on to a computer system or generates a report) or in real time (e.g. when an alert is generated

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without input from the user). The alerts may be based on BG measurements alone or on integration of various clinical variables such as age, weight, laboratory results and current treatment [25], but such systems necessitate fully integrated hospital electronic clinical information systems. Although most systems alert the treating staff at the point of care, some electronic alert systems directly alert a specialist diabetes team. Two studies have evaluated an electronic alert system that generated an automated referral and subsequent consultation by a specialist diabetes team. There was a modest decrease in mean BG (0.7 mmol/l) in one study [26], and a 20% decrease in the proportion of patient-days with mean BG >15 mmol/l in another [27]. These alert systems require complex integrated hospital electronic systems, and demand greater resources and staffing. In contrast, the simple glucose alert system investigated in the present study provides real-time electronic visual alerts and structured recommendations to the treating staff at the point of care. This is an example of a less resource-intensive alert system, which is more likely to be applicable in a wider variety of hospital settings.

Our glucose alert system did not decrease hypoglycaemia, similar to other systems which alerted the treating team [15,24]. Hypoglycaemia is less common than hyperglycaemia; therefore a longer duration of study may be required to detect improvements in hypoglycaemia. Nevertheless, it is reassuring that this intervention, which intensified staff responses to hyperglycaemia, did not concomitantly increase hypoglycaemia. A larger study by Rajendran *et al*. [29] showed that a comprehensive diabetes care pathway, significantly decreased the proportion of patients with severe hypoglycaemia (BG <3 mmol/l) from 15.4% to 9.7%, but that intervention was multi-faceted; it included an extensive education campaign, new subcutaneous insulin prescription and BG observation charts, as well as increased staffing levels [29]. Similarly, Rushakoff *et al.* [28] implemented a comprehensive glycaemic management service where a specialist inpatient diabetes team remotely identified patients with adverse glycaemia, and provided a consultation note, effectively acting as a glucose alert system. This service was associated with a 36% decrease in patient-days with hypoglycaemia, along with a decrease in hyperglycaemia. These studies suggest more resources and staffing may be required to decrease hypoglycaemia [28].

A limitation of the present study is its observational format, which may be more susceptible to a 'Hawthorne effect' on clinical practice because staff were more likely to take action whilst aware that a clinical study was being undertaken. Nevertheless the changes in staff

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responses observed were associated with a decrease in the number of hyperglycaemic episodes. This study was of relatively short duration and thus less susceptible to any influence from hospital-wide changes in staff or hospital processes.

To fully address the problem of managing diabetes in the hospital it is important to appreciate and address each step required to identify and treat adverse glycaemia. Recognizing clinical inertia and alerting adverse glycaemia to health professionals is the first step and cornerstone for improving diabetes care in the hospital. Implementing a practical and novel glucose alert system, the GAP with glucose-alert-capable networked BG meters, can address clinical inertia in the management of inpatients with diabetes in the non-critical care setting. The glucose alert system improved both nursing and medical staff responses to adverse glycaemia and decreased episodes of hyperglycaemia. Glucose alert systems could become important components of larger hospital-wide intensive management strategies required to improve the care of persons with diabetes admitted to hospital.

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Conflict of interest

None declared.

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FIG. 1 Melbourne Glucose Alert Pathway (GAP). BG, blood glucose.

FIG. 2. (a) Patient-days with any blood glucose (BG) value in the severe hyperglycaemia (>15 mmol/l), or critical hyperglycaemia (>20 mmol/l) range. (b) Patient-days with mean BG >10 or >15 mmol/l. Baseline period represented with filled bars and intervention period represented as open bars.

Table 1 Summary of participant characteristics

	Baseline (n = 70)	Intervention (n = 78)	P
Mean ± SD age, years	70±14	68±14	0.90
Men, *n* (%)	48 (69)	52 (68)	0.99
Mean ± SD BMI	29 ± 7	30 ± 7	0.58
Median (IQR) modified* Charlson comorbidity index	2 (0, 4)	2 (1, 4)	0.89
Diabetes type, *n* (%)			0.40
Type 2 diabetes	60 (86)	72 (92)	
Type 1 diabetes	4 (6)	3 (4)	
Other (e.g. steroid-induced, pancreatic)	6 (8)	3 (4)	
Diabetes treatment prior to admission, *n* (%)			0.33
Diet only	16 (23)	11 (14)	
Oral and glucagon-like peptide-1	31 (44)	42 (54)	
Insulin-requiring	23 (33)	25 (32)	
Mean ± SD HbA_{1c}, mmol/mol	54 ± 15	60 ±17	0.06
Mean ± SD HbA_{1c}, %	7.1 ± 1.4	7.6 ± 1.6	
Mean ± SD admission eGFR, ml/min/1.73m^2	71 ± 19	69 ± 22	0.53
Elective admission, *n* (%)	34 (49)	36 (46)	0.87
Admission unit, *n* (%)			0.35
Surgical	52 (74)	64 (82)	
Vascular surgery	21 (30)	21 (27)	
Urology surgery	20 (29)	26 (33)	
Other surgery	11 (16)	17 (22)	
Medical	18 (26)	14 (18)	
Median (IQR) observed patient-days per patient	3.8 (2.1, 7.8)	3.2 (1.8, 6.3)	0.18

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Median (IQR) BG measurements per patient-day	4 (2, 5)	4 (2, 5)	0.10
Insulin regimen on admission to ward, *n* (%)			0.99
No insulin treatment	43 (61)	48 (62)	
Insulin treatment: basal ± bolus	10 (14)	11 (14)	
Insulin treatment: pre-mixed	11 (16)	12 (15)	
Insulin treatment: supplemental only	6 (9)	7 (9)	

BG, blood glucose; eGFR, estimated GFR; IQR, interquartile range.

*Excludes items related to diabetes.

Table 2 Staff response to adverse glycaemia episodes

	Baseline	**Intervention**	***P* ***
1.1.1 Number of episodes of adverse glycaemia (BG >15 or <4 mmol/l)	**101**	**67**	
Nursing response, % (*n*)	45 (45)	73 (49)	<0.001
Medical response, % (*n*)	49 (49)	67 (46)	0.011
Types of medical responses, % (*n*)			
Review of BG measurements	41 (41)	63 (42)	
Revision of diabetes treatment (adjustment of medications or insulin and prescription of correctional insulin)	32 (32)	45 (30)	
Referral to specialist inpatient diabetes team	19 (19)	16 (11)	
1.1.2 Number of episodes of severe hyperglycaemia (BG> 15.0 mmol/l)	**85**	**51**	
Nursing response, % (*n*)	47 (40)	75 (38)	0.002
Medical response, % (*n*)	49 (42)	69 (35)	0.032
1.1.3 Number of episodes of hypoglycaemia (BG <4.0 mmol/l)	**24**	**20**	
Nursing response, % (*n*)	50 (12)	70 (14)	0.227
Medical response, % (*n*)	46 (11)	70 (14)	0.135

BG, blood glucose.

*Fisher's exact test.

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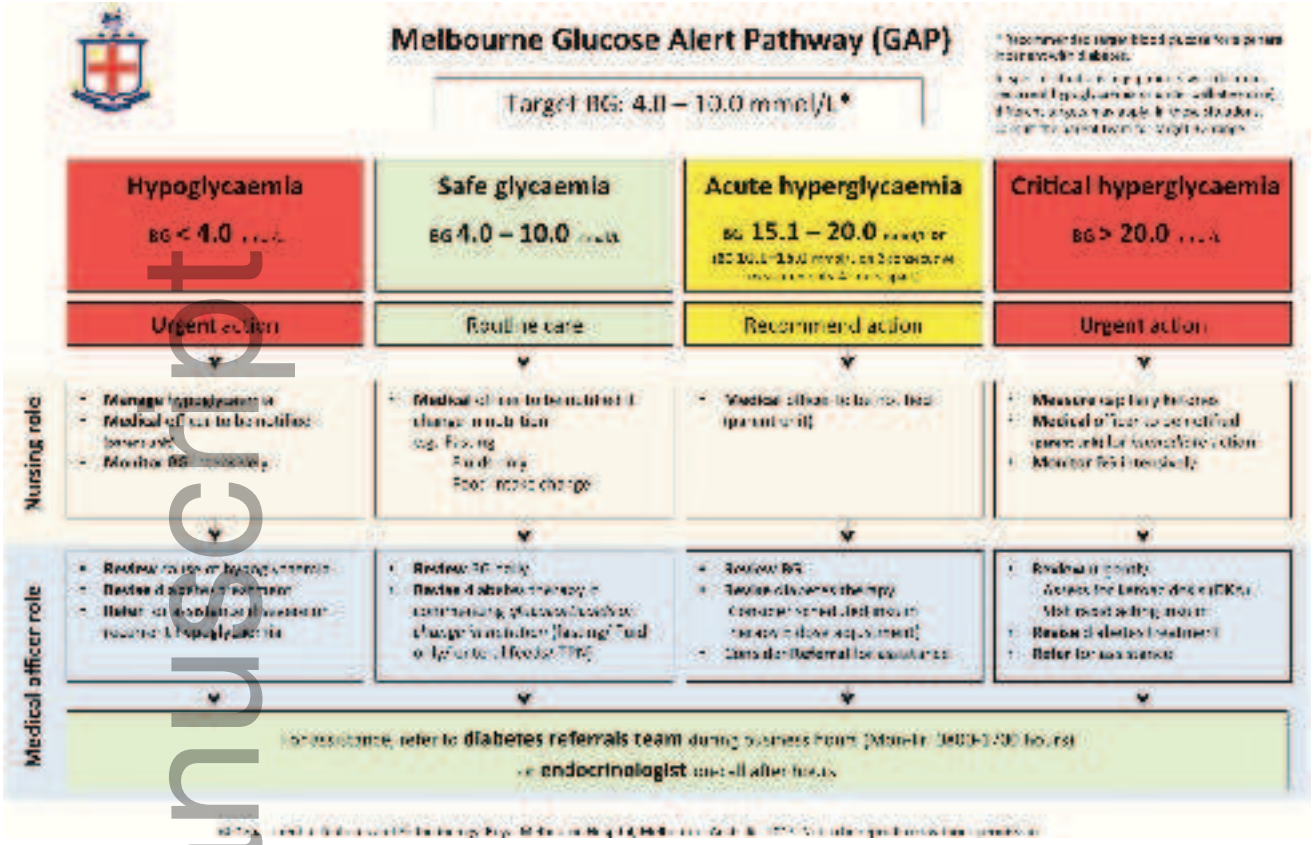

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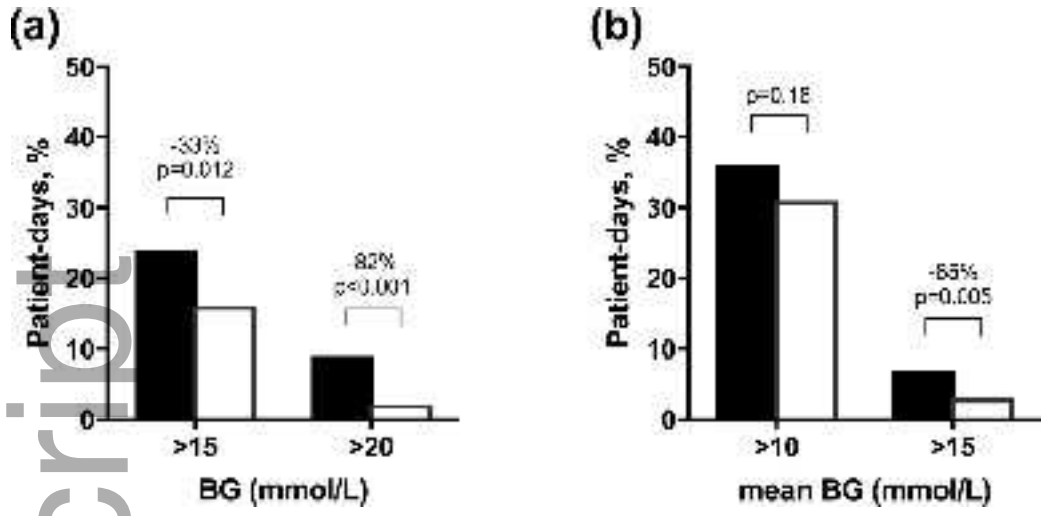

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