JAC-Antimicrobial Resistance

Differential antibiotic dosing in critical care: survey on nurses' knowledge, perceptions and experience

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Background: With the discovery of new antibiotics diminishing, optimizing the administration of existing antibiotics has become a necessity. Critical care nurses play a crucial role in combating antimicrobial resistance and are involved in preparing and administering antibiotics as well as monitoring their effects on patients. A dosing strategy proposed to reduce the development of ever-evolving antimicrobial resistance involves differential dosing regimens such as prolonged/continuous infusions.

Objectives: To assess critical care nurses' knowledge, perceptions, comfort and experience in relation to prolonged/continuous infusion antibiotics.

Methods: A descriptive cross-sectional study was conducted using an investigator-developed, self-administered survey consisting of open- and closed-ended questions. Obtained data were computed using SPSS. Descriptive and inferential statistics were used to analyse the data.

Results: Fifty-two critical care nurses participated in the survey. Data revealed that nurses have adequate levels of knowledge and comfort relating to the use of prolonged/continuous infusion antibiotics along with the ability to communicate effectively on the topic. Results indicate there is a need for further learning, especially in terms of multiplicity of methods for preparing and administering prolonged/continuous infusions and dose calculations. Overall, results are promising as nurses support the wider implementation of prolonged/continuous infusion treatment regimens in critical care.

Conclusion: Although critical care nurses had a good understanding surrounding the use of prolonged/continuous infusion antibiotics, there is a need for further learning beyond information gained from nursing education courses. Findings from this study indicate that nurses are supportive of prolonged/continuous infusion antibiotics. However, further research is needed to determine the most effective mode of antibiotic administration.

Introduction

Antibiotic resistance is on the rise and shows no signs of receding.[1] This has implications for medical procedures from routine surgery to complicated transplant and chemotherapy, as the ability of antibiotics to prevent and treat infection in these cases is greatly impacted.[2] With the discovery of new antibiotics diminishing, optimizing the administration of broad-spectrum antibiotics has become a necessity. A dosing strategy proposed to reduce the development of resistance involves differential dosing regimens such as prolonged/continuous antibiotic infusions (P/CIs).[1]

Although the optimal mode of β-lactam administration remains controversial, meta-analyses comparing P/CI and intermittent infusions (IIs) in critically ill patients have shown that P/CIs offer improved clinical outcomes and decreased hospital mortality.[3,4] Studies comparing antibiotic administration via P/CI versus traditional II have demonstrated significant differences between the two dosing regimens.[5–9] Trials including the β-Lactam InfusioN Group (BLING) and β-Lactam Infusion in Severe Sepsis (BLISS) were specifically designed to overcome the criticisms of prior studies. Collectively, these represent the least heterogeneous and highest-quality evidence available to date demonstrating better attainment of pharmacokinetic/pharmacodynamic targets as well as higher clinical cure rates in the P/CI arm.[10]

Despite these theoretical advantages, a global practice shift towards P/CI antibiotics has not taken place. This is mostly because of the preconceptions that they are more complicated and can

increase staff workload. This is coupled with the uncertainty around the stability of antibiotic infusion solutions.[11]

Nursing plays a key role in supporting efforts to reduce antibiotic resistance. Nurses are first responders, central communicators and coordinators of care for antibiotic therapy. They are integral providers of comfort that monitor the patient's status, safety and response to antibiotic treatment.[12,13] As nurses are the first point of contact for patients, they promote prevention and the subsequent need for antibiotics.

Depending on the circumstances and the scope of practice, nurses can undertake advanced roles, e.g. nurses can be instrumental in leading antimicrobial improvement initiatives like P/CI antibiotic therapy in ICU settings.[14] The appropriate use and administration of antibiotics in ICUs could reduce mortality and morbidity as well as impede the development of difficult-to-treat antibiotic-resistant organisms.[15]

ICU nurses play a crucial role in the rational use of antibiotics, preventing the emergence and spread of antibiotic-resistant bacteria through antibiotic stewardship and infection control programmes.[16,17] They are involved in preparing, administering and prescribing antibiotics as well as monitoring their effects on patients.[14] Statistics on nurses' own perspectives regarding antibiotic knowledge contribute significantly to educational preparation and quality in healthcare. It is important that nurses practising in ICU settings take an active role in ensuring their knowledge of developments and advancement in antimicrobial stewardship remains up to date. Therefore, the purpose of this study was to assess ICU nurses' level of knowledge on antibiotic use in critical care settings and perceptions on antibiotic preparation and administration, as well as to assess their comfort and experience concerning P/CI antibiotic therapy.

Methods

This was a cross-sectional study investigating the knowledge, perceptions and workload of nurses working within ICUs. This study was conducted using an investigator-developed, self-administered survey instrument.

Setting and subjects

The study was conducted at St George's Hospital (SGH) ICU wards: neuro, cardiac and general. All day-shift critical care nurses, both full and part time, from three ICU wards were invited to participate.

Survey instrument

The survey had 21 questions: 5 open-ended and 16 closed-ended Likert scale questions. Closed-ended questions allowed comparison between respondents' responses whereas utilizing open-ended questions gave respondents the opportunity to frame their answers in their own words. The instrument was divided into five sections: (i) demographics, (ii) knowledge, (iii) perceptions, (iv) comfort and (v) experience (Supplementary data, available at *JAC-AMR* Online). The instruments utilized included the following.

The Demographics section included two questions that pertained to nursing years of ICU experience and nurse band grading.

The Knowledge section included three questions that related to nurses' knowledge: two used a five-point Likert scale to assess knowledge of ICU antibiotic administration and one was an open-ended question on nurses' opinions of why P/CIs are used.

The Perceptions section included eight questions associated with nurse perceptions on the preparation and administration of P/CI. Nurses' opinions on the impact different dosing regimens had in terms of workload, time consumption and ease of preparation and delivery were considered, to gain an insight into how these factors influence, guide and support their practice.

The Comfort section included three questions on nurse comfort discussing antibiotic treatment and interpreting microbiology results, which used a five-point Likert scale.

The Experience section included five questions that pertained to nurse experience: one used a five-point Likert scale and four were open-ended questions to gain an insight into the advantages and disadvantages of P/CI as well as investigate nurse opinions of what changes could be made to improve the preparation and administration of P/CI.

Ethical considerations and negotiation of access

Audience-appropriate language was utilized to write survey questions and the respondents were informed on the nature and purpose of the research. Collected information was utilized for the intended purpose of the study. The main ethical issues were respondents' anonymity and confidentiality. The names, addresses and dates of birth of respondents were unrecorded, making collected data anonymous. The survey data were kept confidential and respondents were assured of their right to withdraw at any time.[18–20]

Sample size determination

The aim of this study was to yield useful information about nurses' perceptions on antibiotic therapy in ICU settings. To fulfil the research objectives proposed, a cross-sectional survey design was utilized. A total population of 75 nurses working within three ICUs at SGH were open to voluntary participation in the survey.

A sample size calculation was utilized to ensure attainment of a representative sample size to draw meaningful conclusions that are statistically significant. A sample size of at least 43 participants would be necessary to draw meaningful conclusions that are statistically significant.

Survey procedure

The investigator-developed survey described in the Survey instrument section was distributed to all nurses ($n = 75$) that work during the day in three ICU units at SGH. Prior to distribution, the survey questions and participant information sheet, explaining the purpose and confidentiality of the survey, were approved by the head nurse at SGH.

Data collection and analysis of data

Data collection took place between 12 February and 26 February 2018. Data were computed and processed using Statistical Package for the Social Sciences (SPSS) software version 24 and Microsoft Excel 2010. This study used descriptive and inferential (parametric and non-parametric) statistics to analyse the data.

Statistical analysis

Descriptive analysis of all survey variables was carried out by using absolute and percentage frequencies. Inferential statistics involved conducting parametric and non-parametric statistical analysis. The association and correlation between ranked variables were determined using Cramer V (V) (measure of association between two nominal values) and Kendall's tau-b (τb) non-parametric coefficient statistics. The association and correlation between ranked and ordinal data were determined by employing the γ and Kendall's τb statistics. The non-parametric test Spearman's rank correlation (r_s) was utilized to determine the monotonic relationship between ordinal variables.

Association and correlation parameters

A Cramer's *V* level of association of 0.0–0.1 represents weak association, 0.1–0.3 indicates moderate association and ≥0.3 represents a strong association.

A Kendall's τb correlation coefficient of 0.10–0.29 represents a small association, 0.30–0.49 represents a medium association and ≥0.50 represents a large association or relationship.

A γ value of 0.00–0.30 represents a weak association, 0.40–0.60 indicates a moderate relationship and >0.6 represents a strong association between variables.

For Pearson [$r(50)$] and Spearman's (r_s) correlation, 0–0.3 indicates negligible correlation, 0.4–0.5 represents low correlation, 0.5–0.7 represents moderate correlation and 0.7–1.0 indicates high correlation.

Results

A total of 52 critical care nurses participated in the survey (response rate: 69.3%). Table 1 displays nurse responses to closed-ended Likert-scale questions. Demographic data and survey questions correlations and associations were performed using parametric (Pearson product-moment correlation) and non-parametric (Cramer *V*, Kendall's τb and Spearman's rank correlation) statistics depending on the distribution and the skewness of the data (Table 1).

Statistical analysis

Demographics

The majority of participating nurses (71.2%) had ≥3 years' experience working in ICUs and in band 5 (76.9%) (Table 1). Every year nurses move up their band by one increment: experience, further training and clinical knowledge aid in the achievement of each stage. There are eight increments in band 5 and nine increments in band 6. The results showed that 15.4% (8/52) of nurses were in band 7 (deputy ward manager or ward manager) and 7.7% (4/52) nurses were in band 8. This indicated a very experienced group of respondents.

Correlations and association between ranked variables (years of ICU experience and band grading) indicated a strong, positive relationship ($V = 0.578$ and τb $= 0.719$; correlation significant to the 0.01 level).

Knowledge

The majority of nurses considered their knowledge of antibiotic use in the ICU to be 'very good' or 'good' (77%) and similarly for antibiotic administration via P/CI (80.8%) (Table 1). Nurses stated that P/CIs are used to improve efficacy of antibiotics (33%), maintain antibiotic levels above the MIC (32%) and aid in preventing antimicrobial resistance (31%). A few respondents (4%) mentioned that administering via P/CI would reduce the need for regular dosing (Figure 1).

The association and correlation between ICU experience and knowledge displayed a very weak, non-significant association and correlation between (i) ICU experience and administration knowledge ($\gamma = -0.085$ and τb $= -0.059$) and (ii) band grading and administration knowledge ($\gamma = 0.044$ and τb $= 0.029$).

Perceptions

Nurses perceived P/CIs advantageous over conventional intermittent infusions. Participants responded that P/CI antibiotics aid in achieving higher clinical cure rates (88%). From the 52 participants, 92.3% believed that antibiotic preparation for P/CI does not increase workload nor is it more time consuming when compared with conventional II. The majority of participants also found that antibiotic administration via P/CI does not increase workload (82.7%) nor is it more time consuming (69.2%). However, respondents did not find the preparation and administration of P/CI antibiotics easier than IIs. All but four nurses believed that P/CI antibiotics are not more prone to medical errors. Of the four nurses, three put medical errors down to calculation error and one believed these errors were due to multiple manipulations (Table 1).

Nurses that stated their knowledge on P/CI of antibiotics was 'good' or 'very good' also believed that P/CIs aid in achieving higher clinical cure rates compared with conventional IIs ($r_s = 0.453$, $P < 0.01$). There is a strong positive association between 'nurse knowledge on antibiotic modes of administration' and 'the achievement of higher clinical cure rates when administration is via prolonged/continuous infusions' ($\gamma = 0.679, P < 0.01$).

Overall, nurses did not feel that P/CI increased their workload. A strong positive association between participant responses to statements 7 and 8 (Supplementary data) ($\gamma = 0.981$, $P < 0.01$; τb $= 0.727$, $P < 0.01$) was observed, where nurses who thought that antibiotic preparation for P/CI did not increase workload also thought that preparation for this dosing regimen did not take more time. Nurses who also found that the administration of antimicrobials via P/CI did not involve additional workload observed that this dosing regimen was not more time consuming ($\gamma = 0.907$, $P < 0.01$; τb $= 0.583, P < 0.01$).

Respondents who specified that the preparation of antibiotics for P/CI did not increase workload also stated that administration via this dosing regimen did not increase workload ($\gamma = 0.925$, $P < 0.01$). Nurse that stated P/CI preparation was not more time consuming also thought that administration utilizing this dosing regimen did not consume more time when compared with II ($\gamma = 0.661, P = 0.01$).

Comfort

Most nurses considered themselves comfortable (i) discussing antibiotic therapy (80.7%), (ii) discussing laboratory results related to infection (86.5%) and (iii) interpreting microbiology results (76.9%). However, a significant number of nurses were neutral: 19.2%, 11.5% and 15.4%, respectively (Table 1).

Nurse who were comfortable discussing antibiotic therapy were also comfortable discussing laboratory data with other healthcare professionals [$r(50) = 0.513$, $P < 0.01$; $\gamma = 0.778$, $P < 0.01$] and interpreting microbiology results [$r(50) = 0.426$, $P < 0.01$; $\gamma = 0.638$, $P < 0.01$]. Respondents who were comfortable discussing patient laboratory results were also comfortable interpreting microbiology results [$r(50) = 0.442, P = 0.01; \gamma = 0.715, P < 0.01$].

Also, nurses that believed P/CI of antibiotics aided in achieving higher clinical cure rates were more comfortable (i) discussing antibiotic therapy with healthcare professionals ($r_s = 0.460$, $P < 0.01$; $\gamma = 0.675$, $P < 0.01$), (ii) discussing laboratory results related to infection with other healthcare professionals ($r_s = 0.549$, $P < 0.01$;

Table 1. Nurses' responses to the closed-ended Likert-scale questions in terms of (i) demographics, (ii) knowledge, (iii) perceptions, (iv) comfort and (v) experience, and distribution and skewness of survey data

Statement	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%	D	S
Demographics	<1 year		1–3 years		3–5 years		5–10 years		>10 years			
How long have you worked in ICU?	8	15.4	7	13.5	9	17.3	12	23	16	30.8		
Knowledge	very poor		poor		acceptable		good		very good			
My general knowledge about antibiotics in the intensive care unit is. . .	0	0	0	0	12	23.1	32	61.5	8	15.4	ND	0.048
My general knowledge about administering antibiotics via prolonged/ continuous infusions is. . .	0	0	2	3.8	8	15.4	31	59.6	11	21.2	ND	−0.606
Perceptions	strongly disagree		disagree		uncertain		agree		strongly agree			
Prolonged/continuous infusions of antibiotics aids in achieving higher clinical cure rate compared with conventional intermittent infusions	1	1.9	0	0	5	9.6	20	38.5	26	50	NS	−1.636
The preparation of antibiotics for prolonged/continuous infusions results in an increased workload on nurses compared with conventional intermittent infusions	5	9.6	43	82.7	3	5.8	1	1.9	0	0	PS	1.072
The preparation of antibiotics via prolonged/continuous infusions is more time consuming compared with conventional intermittent infusions	6	11.5	42	80.9	0	0	4	7.7	0	0	PS	1.698
Prolonged/continuous infusions are easier to prepare compared with conventional intermittent infusions	3	5.8	34	65.4	8	15.4	6	11.5	1	1.9	PS	1.193
The administration of antibiotics by prolonged/continuous infusions results in an increased workload on nurses compared with conventional intermittent infusions	3	5.8	40	76.9	0	0	9	17.3	0	0	PS	1.373
The administration of antibiotics via prolonged/continuous infusions is more time consuming compared with conventional intermittent infusions	4	7.7	32	61.5	1	1.9	15	28.8	0	0	ND	0.618
Prolonged/continuous infusions are easier to administer compared with conventional intermittent infusions	2	3.8	38	73.1	6	11.5	5	9.6	1	1.9	PS	1.615
I think that the preparation of continuous infusion antibiotics is more prone to medical errors	yes		no		not sure							
	4	7.7	46	85.5	2	3.8						
	multiple manipulations		calculations		other							
If yes, why?	1	25	3	75	0	0						

Continued

Table 1. *Continued*

Statement	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%	D	S
Comfort	very uncomfortable		uncomfortable		neutral		comfortable		very comfortable			
I am comfortable discussing antibiotic therapy with other healthcare professionals	0	0	0	0	10	19.2	32	61.5	10	19.2	ND	0.000
I am comfortable discussing laboratory results related to infections with other healthcare professionals	0	0	1	1.9	6	11.5	36	69.2	9	17.3	ND	−0.547
I am comfortable interpreting microbiology results	0	0	4	7.7	8	15.4	30	57.7	10	19.2	ND	−0.711
Experience	strongly disagree		disagree		uncertain		agree		strongly agree			
I routinely conduct visual inspection for of the antibiotics being administered as prolonged/continuous infusions for precipitation throughout the infusion time	0	0	4	7.7	4	7.7	17	32.7	27	51.9	ND	−0.981

D, distribution; S, skewness; ND, normal distribution; NS, negatively skewed; PS, positively skewed.

$\gamma = 0.869$, $P < 0.01$) and (iii) interpreting microbiology results ($r_{s} = 0.778$; $P < 0.01$; $\gamma = 0.561$, $P < 0.01$).

The relationship between 'knowledge of administering antibiotics via prolonged/continuous infusion' and 'comfort in terms of discussing antibiotic therapy with other healthcare professionals' was determined. Nurses who perceived their knowledge as 'very good' and 'good' felt more comfortable discussing antibiotic therapy [$r(50) = 0.387$, $P < 0.01$; $\gamma = 0.664$, $P < 0.01$]. Participants who perceived themselves knowledgeable about antibiotic therapy in ICU were also comfortable interpreting microbiology results [$r(50) = 0.451$, $P < 0.01$]. There was a strong, positive association between knowledge and comfort ($\gamma = 0.703$, $P < 0.01$).

A Pearson product-moment correlation and a γ statistic test to determine the relationship between nurses' general antibiotic knowledge in ICU and comfort levels in terms of discussing laboratory results related to infection found a positive correlation [$r(50) = 0.314$, $P < 0.05$] and association ($\gamma = 0.548$, $P < 0.01$).

Experience

We found that 84.6% of participants 'strongly agree' (32.7%) or 'agree' (51.9%) that visual inspection of the antibiotic's physical compatibility during the infusion time of a P/CI should be conducted. Of the remaining respondents, 7.7% (4/52) were 'not sure' and 7.7% (4/52) disagreed (Table 1). Responses to open-ended questions are displayed in Figure 1.

Interestingly, years of ICU practice [$r(50) = 0.054$, $P = 0.7$; $\gamma = 0.197$, $P < 0.5$], band grading [$r(50) = 0.246$, $P < 0.01$; $\gamma = 0.246$, $P < 0.2$] and comfort [$r(50) = 0.374$, $P < 0.01$; $\gamma = 0.338$, $P = 0.06$] were not predictive of experience. However, a positive correlation and association between knowledge and experience was found. Routine visual inspection of antibiotics being administered via P/CI was carried out by nurses who perceived they were

knowledgeable in terms of (i) antibiotics in ICUs [$r(50) = 0.356$, $P = 0.01$; $\gamma = 0.457$, $P < 0.05$] and (ii) administering antibiotics via P/CI [$r(50) = 0.357$, $P = 0.01$; $\gamma = 0.544$, $P < 0.01$].

Discussion

To our knowledge, this is the first study to assess ICU nurses' knowledge, perceptions, comfort and experience on antibiotic preparation, administration and use in critical care settings. The appropriate use and administration of antibiotics in critical care settings could reduce mortality and morbidity as well as impede the development of difficult-to-treat antibiotic-resistant organisms.[15]

Overall, the results revealed that nurses have adequate levels of knowledge and comfort relating to the use of P/CI antibiotics along with the ability to communicate effectively on the topic. This is promising as it supports the wider implementation of P/CI treatment regimens in critical care.

Knowledge accrued through professional practice and life experiences influences a nurse's ability to obtain and use knowledge.[21] Studies have confirmed that experienced nurses use multiple sources of knowledge to guide their practice.[15,21,22] Interestingly, results obtained in this study revealed that the years of ICU experience or banding position were not predictive of the nurse's self-perception of knowledge on antibiotic therapy.

Studies have shown that P/CI may offer improved clinical outcomes when compared with II, given that the majority of studies published demonstrated improved clinical cure rates or a significant difference between the two dosing regimens.[5-9] Respondents stated that P/CI of antimicrobials aided in achieving higher clinical cure rates when compared with traditional bolus infusions (88.5%), agreeing with previous clinical studies that recommend this mode of administration for patients with severe infection (in the ICU) or patients infected by less susceptible microbes.[8,9,23]
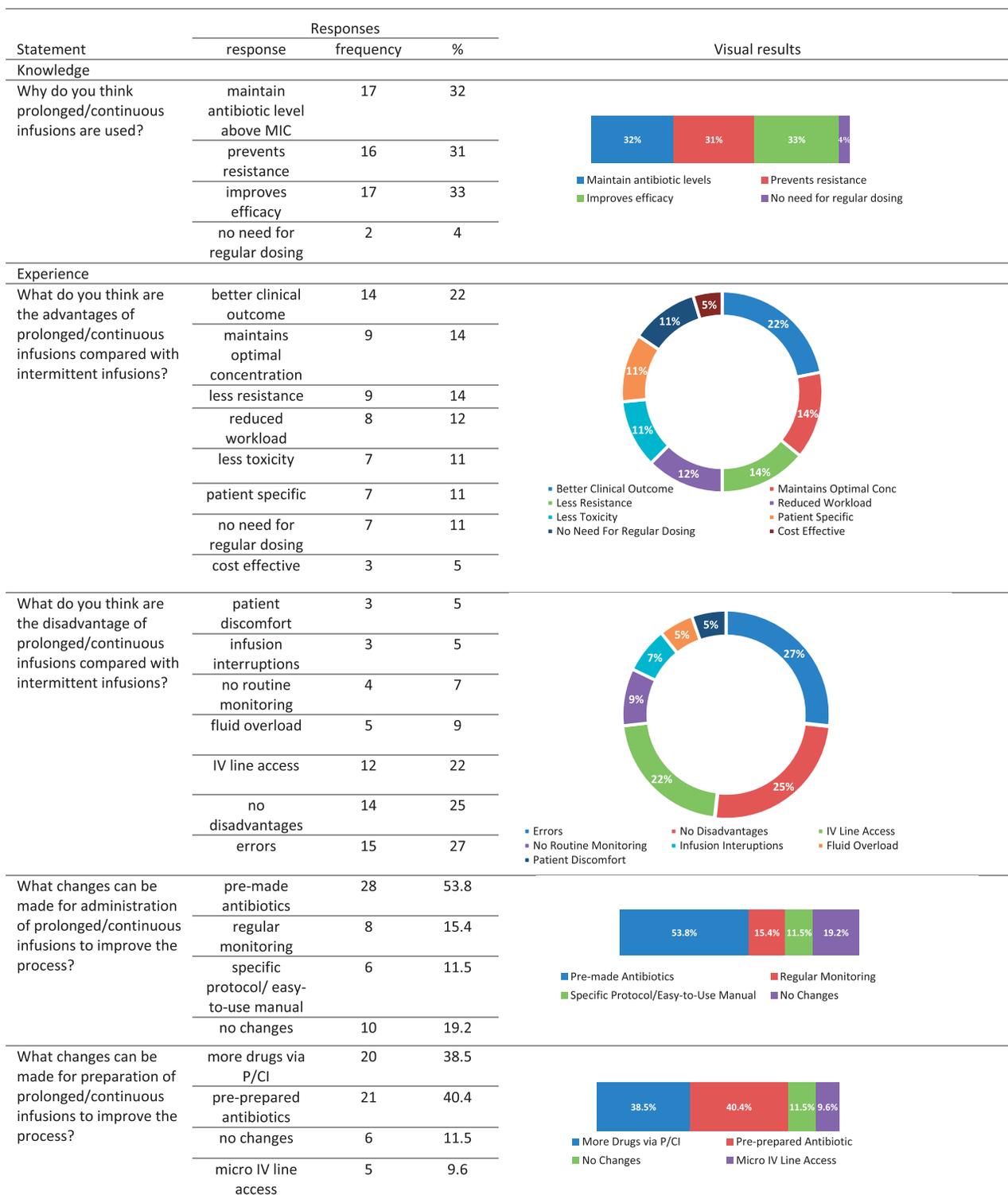
Statement	Responses response	frequency	%	Visual results
Knowledge				
Why do you think prolonged/continuous infusions are used?	maintain antibiotic level above MIC	17	32	
	prevents resistance	16	31	
	improves efficacy	17	33	
	no need for regular dosing	2	4	
Experience				
What do you think are the advantages of prolonged/continuous infusions compared with intermittent infusions?	better clinical outcome	14	22	
	maintains optimal concentration	9	14	
	less resistance	9	14	
	reduced workload	8	12	
	less toxicity	7	11	
	patient specific	7	11	
	no need for regular dosing	7	11	
	cost effective	3	5	
What do you think are the disadvantage of prolonged/continuous infusions compared with intermittent infusions?	patient discomfort	3	5	
	infusion interruptions	3	5	
	no routine monitoring	4	7	
	fluid overload	5	9	
	IV line access	12	22	
	no disadvantages	14	25	
	errors	15	27	
What changes can be made for administration of prolonged/continuous infusions to improve the process?	pre-made antibiotics	28	53.8	
	regular monitoring	8	15.4	
	specific protocol/ easy-to-use manual	6	11.5	
	no changes	10	19.2	
What changes can be made for preparation of prolonged/continuous infusions to improve the process?	more drugs via P/CI	20	38.5	
	pre-prepared antibiotics	21	40.4	
	no changes	6	11.5	
	micro IV line access	5	9.6	

Figure 1. Nurses' responses to open-ended questions. P/CI, prolonged/continuous infusion.

Respondents were able to categorize intrinsic factors (e.g. prevents antimicrobial resistance and improves antibiotic efficacy) and extrinsic factors (cost/time saving and patient's length of hospital stay) known to be associated with antibiotic administration via P/CI that corroborate the literature.[8,24–26] Nurses stated that P/CIs reduced the need for regular dosing and hence are beneficial for both patients and nurses as they reduce the patient's discomfort and, on some occasions, the nurse's workload.

The preparation of P/CI takes place on the wards mostly by nursing staff and involves calculations, multiple manipulations, dilution after reconstitution and use of infusion bags/pumps.[27] The multiplicity of methods for preparing antibiotics for continuous administration creates a situation where mistakes may easily occur. Nurses affirmed that the preparation and administration of antibiotics for P/CI is more intricate in comparison with II preparation and administration; however, they did not believe it was more time consuming or associated with increasing workload. It is evident that the use of P/CI requires multiple manipulations compared with traditional II due to the need for multiple steps, loading doses, more complex calculations and more stringent monitoring.[28]

Studies indicate that drug equilibration takes longer in P/CI than bolus administration, delaying the onset of antibacterial activity.[6,8,9,29] Thus, this can be circumvented by the administration of an initial loading dose. Although the loading dose ensures the rapid onset of antibacterial activity, the preparation of two doses is needed to initiate patient antibiotic therapy.[30] However, respondents did not identify the preparation or administration of P/CI to be more time consuming or to increase workload.

A vital skill required is the ability to calculate the antibiotic doses prescribed; however, the most recurrently cited error resulting in the wrong dose being administered stems from miscalculating doses.[31] Of participants that 'agreed' (4/52) that this dosing regimen is more prone to medical errors, however, 75% (3/4) believed it was due to calculation errors. When calculating and preparing the correct dose for a patient, nurses need to understand the different measurements used for drug dosages and be able to convert between different units of measurement.[31] A series of decimally related dilutions for preparing individual antibiotic dosages that are patient specific require skills and additional effort. For example, with some ICU patients in whom severe fluid restriction may be necessary, solutions double or quadruple the strength are prepared.[27]

To ensure the safe IV delivery of infusion antibiotics, nurses must be observant for potentially dangerous precipitates often caused by drug or diluent incompatibilities. Some respondents (15%) do not conduct visual inspection of the physical compatibility of antibiotics administered via P/CI. Nurses should identify and avoid drug incompatibilities when preparing and administering antibiotics and monitor infusions adherently.[32]

Although most respondents considered their knowledge, comfort and experience satisfactory, there is a need for further learning beyond information gained from nursing education courses. Developing and employing a variety of strategies and mechanisms to improve and update nurses' knowledge on antibiotic dosing regimens used in the ICU is crucial. Educational support including (i) staff presentations, (i) attendance at conferences and (iii) in-ICU educational posters are strategies that could be employed to raise awareness of antibiotic use.[33]

The findings of this survey should be interpreted in view of certain limitations. Firstly, this was an investigator-developed survey. Therefore, prior to distribution, the survey questions and participant information sheet were validated and approved by the head nurse at SGH. Secondly, this survey involved in-person dissemination, limiting the exposure of the survey to wider audiences. Thirdly, the survey was completed by day-shift staff and therefore the data obtained do not account for the difference in experience between day- and night-shift nurses. Although the survey was only conducted in day staff, these results provide a realistic view of nurses' knowledge, experience and comfort with antibiotic therapy in critical care settings. Fourthly, the survey was disseminated only in SGH. Although dissemination was conducted in a single setting, the data obtained are representative and included a wide range of nurses from three different ICU wards within the hospital.

Conclusions

Results indicate that ICU nurses at SGH have a good understanding surrounding the use of P/CI antibiotics. Findings from this study indicate that nurses are supportive of P/CI antibiotics. Participants considered their knowledge, comfort and experience with antibiotic therapy high; however, key misperceptions were identified, indicating that nurses may not be aware of their knowledge deficits. Therefore, incorporating education, assessment and reinforcement on nurse competence associated with injection, infusion safety and infection control is required. Further research is needed to determine the most effective antibiotic mode of administration and continued stability studies will aid in ameliorating current dosing regimens to optimize antibiotic efficacy.

Transparency declaration

None to declare.

Supplementary data

The survey is available as Supplementary data at JAC-AMR Online.

References

1 Fawaz S, Dixon B, Barton S et al. Suitability of amoxicillin–clavulanic acid for administration via prolonged infusion. *Drug Des Devel Ther* 2020; **14**: 103–9.

2 Salyers AA, Whitt DD. *Revenge of the Microbes: How Bacterial Resistance is Undermining the Antibiotic Miracle*. ASM Press, 2005.

3 Lal A, Jaoude P, El-Solh AA. Prolonged versus intermittent infusion of β-lactams for the treatment of nosocomial pneumonia: a meta-analysis. *Infect Chemother* 2016; **48**: 81–90.

4 Roberts JA, Davis JS, Abdul-Aziz M-H et al. Continuous versus intermittent β-lactam infusion in severe sepsis. A meta-analysis of individual patient data from randomized trials. *Am J Respir Crit Care Med* 2016; **194**: 681–91.

5 Teo J, Liew Y, Lee W et al. Prolonged infusion versus intermittent boluses of β-lactam antibiotics for treatment of acute infections: a meta-analysis. *Int J Antimicrob Agents* 2014; **43**: 403–11.

6 Jamal JA, Roberts DM, Udy AA et al. Pharmacokinetics of piperacillin in critically ill patients receiving continuous venovenous haemofiltration: a randomised controlled trial of continuous infusion versus intermittent bolus administration. *Int J Antimicrob Agents* 2015; **46**: 39–44.

7 Lorente L, Palmero S, Jos J et al. Comparison of clinical cure rates in adults with ventilator-associated pneumonia treated with intravenous ceftazidime administered by continuous or intermittent infusion: a retrospective, nonrandomized, open-label, historical chart review. *Clin Ther* 2007; **29**: 2433–9.

8 Rafati MR, Rouini MR, Mojtahedzadeh M *et al*. Clinical efficacy of continuous infusion of piperacillin compared with intermittent dosing in septic critically ill patients. *Int J Antimicrob Agents* 2006; **28**: 122–7.

9 Lorente L, Jiménez A, Martín MM *et al*. Clinical cure of ventilator-associated pneumonia treated with piperacillin/tazobactam administered by continuous or intermittent infusion. *Int J Antimicrob Agents* 2009; **33**: 464–8.

10 Zvonar R. Should prolonged infusion of β-lactams become standard of practice? *Can J Hosp Pharm* 2017; **70**: 156–60.

11 Abdul-Aziz MH, Dulhunty JM, Bellomo R *et al*. Continuous β-lactam infusion in critically ill patients: the clinical evidence. *Ann Intensive Care* 2012; **2**: 37.

12 Hale LS, Votaw LL, Mayer JE. Nurses' knowledge, perception, and self-confidence regarding evidence-based antibiotic use in the long-term care setting. *Consult Pharm* 2017; **32**: 700–6.

13 Olans RN, Olans RD, Demaria A. The critical role of the staff nurse in antimicrobial stewardship—unrecognized, but already there. *Clin Infect Dis* 2016; **62**: 84–9.

14 Ladenheim D. Role of nurses in supporting antimicrobial stewardship. *Nurs Stand* 2018; **33**: 55–8.

15 Skår R. Knowledge use in nursing practice: the importance of practical understanding and personal involvement. *Nurse Educ Today* 2010; **30**: 132–6.

16 Rábano-Blanco A, Domínguez-Martís EM, Mosteiro-Miguéns DG *et al*. Nursing students' knowledge and awareness of antibiotic use, resistance and stewardship: a descriptive cross-sectional study. *Antibiotics* 2019; **8**: 203.

17 Jayaweerasingham M, Angulmaduwa S, Liyanapathirana V. Knowledge, beliefs and practices on antibiotic use and resistance among a group of trainee nurses in Sri Lanka. *BMC Res Notes* 2019; **12**: 4–9.

18 Pope C, Mays N. Qualitative methods in health research. In: Pope C, Mays N, eds. *Qualitative Research in Health Care*. Blackwell Publishing, 2006; 1–11.

19 Jones R, Murphy E, Crosland A. Primary care research ethics. *Br J Gen Pract* 1995; **45**: 623–6.

20 Evans M, Robling M, Maggs RF *et al*. It doesn't cost anything just to ask, does it? The ethics of questionnaire-based research. *J Med Ethics* 2002; **28**: 41–4.

21 Rycroft-Malone J, Titchen A, Kitson A *et al*. What counts as evidence in evidence-based practice? *J Adv Nurs* 2004; **47**: 81–90.

22 Bonner A. Understanding the role of knowledge in the practice of expert nephrology nurses in Australia. *Nurs Health Sci* 2007; **9**: 161–7.

23 Yu Z, Pang X, Wu X *et al*. Clinical outcomes of prolonged infusion (extended infusion or continuous infusion) versus intermittent bolus of meropenem in severe infection: a meta-analysis. *PLoS One* 2018; **13**: e0201667.

24 Alou L, Aguilar L, Sevillano D *et al*. Is there a pharmacodynamic need for the use of continuous versus intermittent infusion with ceftazidime against *Pseudomonas aeruginosa*? An *in vitro* pharmacodynamic model. *J Antimicrob Chemother* 2005; **55**: 209–13.

25 Roberts JA, Kirkpatrick CMJ, Roberts MS *et al*. First-dose and steady-state population pharmacokinetics and pharmacodynamics of piperacillin by continuous or intermittent dosing in critically ill patients with sepsis. *Int J Antimicrob Agents* 2010; **35**: 156–63.

26 Lipman J, Gomersall CD, Gin T *et al*. Continuous infusion ceftazidime in intensive care: a randomized controlled trial. *J Antimicrob Chemother* 1999; **43**: 309–11.

27 Burtles R. Continuous infusion of drugs: a simple and rational system. *J Cardiothorac Vasc Anesth* 1991; **5**: 362–4.

28 Sauer P, Van Horn ER. Impact of intravenous insulin protocols on hypoglycemia, patient safety, and nursing workload. *Dimens Crit Care Nurs* 2009; **28**: 95–101.

29 Winstead EM, Ratliff PD, Hickson RP *et al*. Evaluation of an alternative extended-infusion piperacillin–tazobactam dosing strategy for the treatment of gram-negative infections. *Int J Clin Pharm* 2016; **38**: 1087–93.

30 Van Zanten ARH, Oudijk M, Nohlmans-Paulssen MKE *et al*. Continuous vs. intermittent cefotaxime administration in patients with chronic obstructive pulmonary disease and respiratory tract infections: pharmacokinetics/ pharmacodynamics, bacterial susceptibility and clinical efficacy. *Br J Clin Pharmacol* 2006; **63**: 100–9.

31 Wright K, Shepherd E. How to calculate drug doses and infusion rates accurately. *Nurs Times [online]* 2017; **113**: 31–4.

32 Shastay A. Administration of a product with a precipitate. *Home Healthc Now* 2019; **37**: 53–4.

33 Munro CL, Grap MJ. Nurses' knowledge and attitudes about antibiotic therapy in critical care. 2001; **17**: 213–18.