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The influence of nurse cohorting on hand hygiene effectiveness

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Abstract

Direct contact between healthcare staff and patients is generally considered to be the primary route by which most exogenously-acquired infection spreads within and between wards. Hand washing is therefore perceived to be the single most important infection control measure that can be adopted, with the continuing high infection rates generally attributed to poor hand hygiene compliance. Through the use of simple mathematical models, this paper demonstrates that under conditions of high patient occupancy or understaffing, hand washing alone is unlikely to prevent the transmission of infection. The study demonstrates that applying strict nurse cohorting in combination with good hygiene practice is likely to be a more effective method of reducing transmission of infection in hospitals. (115 words)

Key Words

Hand hygiene, handwashing, nurse cohorting, nosocomial infection, hospital acquired infection, MRSA

Article Summary

The paper demonstrates that under conditions of high patient occupancy or understaffing, hand washing alone is unlikely to prevent the transmission of infection.

Introduction

Despite recent medical advances and considerable effort on the part of healthcare providers and regulators, the incidence of hospital acquired infection (HAI) remains high; with approximately 1 in 10 patients acquiring an infection during a hospital stay (1). Direct contact between healthcare staff and patients is generally considered to be the primary route by which many exogenously-acquired infections are spread within and between wards. Hand washing is therefore perceived as being the single most important preventative measure, which can be employed in the fight against infection (2-4). Unfortunately, hand hygiene compliance in many institutions is relatively low (5, 6) and it is this which is thought to be the principal reason why nosocomial infection rates remain so high (2).

A number of studies have found nosocomial outbreaks to be associated with high patient-to-staff ratios (6-10). Others have found increased workload to be associated with decreased hand hygiene compliance (4, 11). It is therefore generally assumed that under conditions of high workload, as might be found in an overcrowded or understaffed ward, outbreaks occur due to poor hand hygiene compliance. While this assumption is in part true, it ignores important logistical issues which can strongly influence the overall effectiveness of hand hygiene measures. In particular, the potentially important relationship between the number of possible transmission pathways and hand hygiene has been largely overlooked. Through the use of simple mathematical models this paper investigates the relationship between staff deployment, ward occupancy and hand hygiene, and demonstrates both the limitations of hand washing and the fundamental importance of nurse cohorting (that is, a system in which nurses care for a limited number of identified patients during a given period of working) in preventing the spread of infection on hospital wards.

Hand Hygiene

While many factors influence the risk of acquiring an infection whilst in hospital, patient-to-patient contact, usually via the unwashed hands of healthcare staff, is generally accepted as being the principal route of transmission for most exogenously acquired infections. Despite this realisation and considerable effort on the part of healthcare providers and regulators, hand hygiene compliance remains relatively low, typically in the region of 40% (12). This has lead to the widespread opinion that HAI rates can be greatly reduced by increased hand hygiene compliance alone (2). However, such thinking assumes that the effectiveness of hand hygiene measures is not limited by other factors. In particular, the relationship between staff deployment and hand hygiene has largely been ignored. Given that; (i) the purpose of hand washing is to avoid the transmission of infection between patients, and (ii) each hand washing event is less than 100% effective, with some microorganisms remaining on hands despite washing (13), it follows that the risk of transmission is influenced by both the efficacy of the hand washing process and the frequency of patient-to-patient interactions made by healthcare workers – the greater the number of interactions the greater the risk of transmitting potentially pathogenic microorganisms. Thus, if a healthcare worker suddenly has to care for a greater than normal number of patients, as might be the case in an understaffed ward, it is more likely that infections will be transmitted even though hand hygiene compliance may remain unchanged.

Mathematical Model

The transmission of many infections can be characterized by the use of a basic reproductive number, R_0, which in this case can be defined as the average number of secondary cases of colonization (which precedes infection) generated by one primary case in the absence of any infection control procedures. Highly transmissible infections will have a large R_0, while for those that are less transmissible the value of R_0 will be smaller. If $R_0 > 1$, then each colonized patient will generate further new cases and it is likely that an outbreak will ensue. The outbreak will continue until R_0 becomes less than 1, at which point it will begin to die out. Infection control practices are therefore designed to reduce the value of R_0 to an effective reproductive number, R, which is a measure of infectivity after any infection control measures have been applied. Infection control measures therefore aim to ensure that $R < 1$, thus minimising the risk of an outbreak.

Austin et al. (14) developed a model which simulated the effect of both hand hygiene and nurse cohorting on the value of R. This model assumed the efficacy of each hand washing event to be 100%, with the probability of hand hygiene compliance being p. In the model healthcare workers are divided into medical staff, who are not cohorted, and nursing staff who are given a cohorting probability, q, which is the probability that the next contact will be with the same patient. The effective reproductive number can therefore be calculated as follows:

$$R = (1 - p)(1 - qn)R_0 \tag{1}$$

Where n is the proportion of nurses amongst the total staff.

While Austin et al's model allows for the probability that healthcare workers will wash their hands, it assumes that each hand washing event is 100% successful. In reality this will not be the case (13). Therefore in order to closely simulate ward behaviour it is necessary to include an additional term, h, which is the average efficacy of each hand washing event.

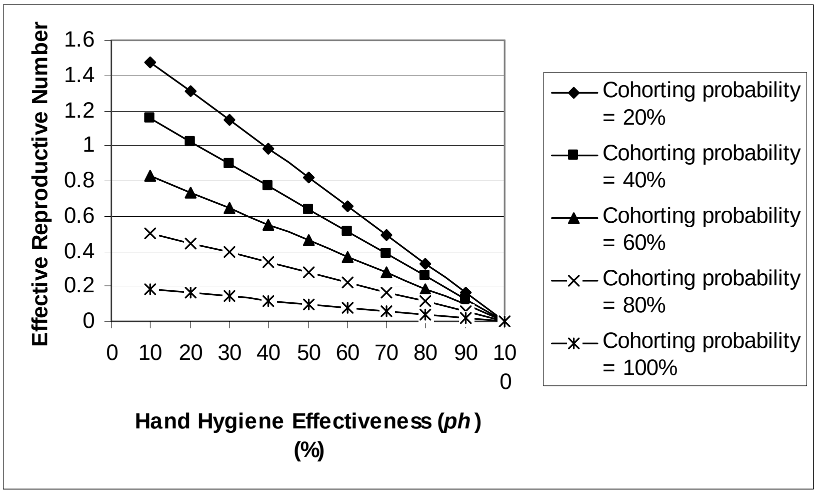
$$R = (1 - ph)(1 - qn)R_0 \tag{2}$$

The product of p and h represents the overall effectiveness of hand hygiene measures.

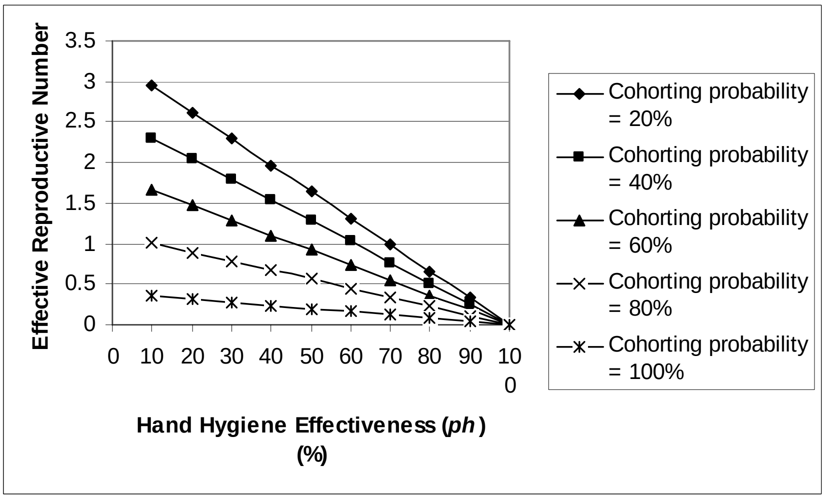
Cohorting and hand hygiene

From Equation 2 it can be seen that the value of R is dependent on both ph and q. So if q is small, as might be the case in an understaffed ward, it will be necessary to increase hand hygiene compliance significantly in order not to increase the risk of transmitting potential pathogens. This point is illustrated by Figure 1, which shows the interaction between cohorting probability, q, and hand hygiene effectiveness, ph. From this it can be seen that as the value of q falls, so it is necessary to increase ph, in order to ensure that $R < 1$. Likewise, it can also be observed that as the value of R_0 increases, so ph must increase substantially in order to ensure that any outbreak dies out. Indeed, if R_0 is high (as in Figure 1(c)), without rigorous nurse cohorting, it would be extremely difficult to control the outbreak by hand hygiene measures alone. It should be noted that very high values of R_0 often signify a transmission by a route other than hand-borne contact (e.g. airborne transmission).

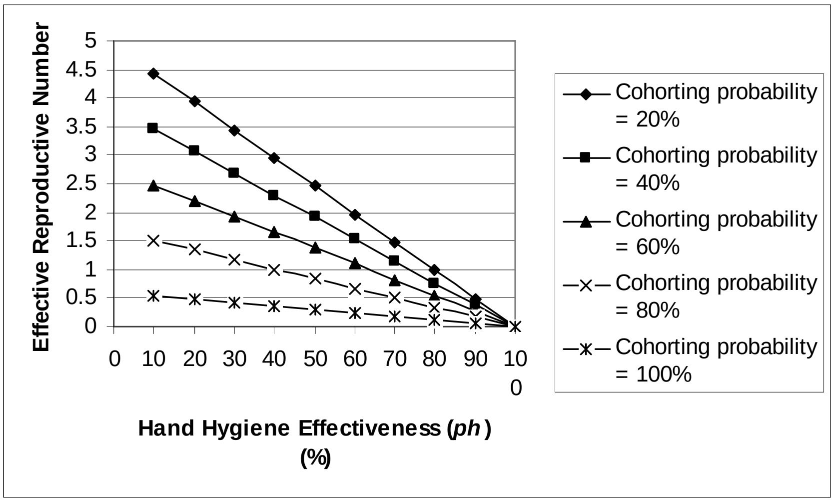
Interestingly, from Figure 1 it can be seen that even if the nursing staff do not move between patients (i.e. $q = 1$), there is still a risk of transmission between patients because the medical staff are not cohorted.



(a) Basic reproductive number, $R_0 = 2$



(b) Basic reproductive number, $R_0 = 4$



(c) Basic reproductive number, R_0 = 6

Figure 1 The influence of hand hygiene effectiveness (*ph*) and cohorting probability (*q*) on the effective reproductive number (*R*), for a range of basic reproductive numbers (R_o) (assuming n = 0.9).

Transmission Pathways

The value of *q* will vary depending on the clinical setting. For example, in an intensive care unit the level of cohorting of nursing staff is thought to be in the region of 80% (15). However, in other settings the value of *q* will be much lower, as the nursing staff often have to attend to many patients. Indeed, cohorting may be almost non-existent in situations where wards are overcrowded or understaffed. In such circumstances a nurse may be required to make many journeys between a large number of patients, with the result that many potential transmission pathways will exist. So the greater the number of patients in a zone served by a single nurse, the greater the number of potential contact routes between the various patients.

With respect to overcrowding, it is possible to estimate the potential increased risk of adding one or more extra beds to a ward. For a ward containing θ occupied beds the number of potential contact routes, T_θ, between patients is given by

$$T_\theta = \theta(\theta - 1) \qquad (3)$$

However not all of these contacts have the potential to result in the transmission of an infection. Some will be nullified by the action of hand washing, the overall effectiveness of which is *ph*. It is therefore possible to modify equation 3 so that the number of contact routes that could potentially result in transmission, TH_θ, (i.e. hazardous contacts) can be calculated.

$$TH_\theta = \theta(\theta - 1)(1 - ph) \qquad (4)$$

It is possible to use Equation 4 to estimate the relative increase in risk resulting from the addition of one or more occupied beds to an existing ward space. For example, a fully occupied four-bedded ward with a hand hygiene effectiveness of *ph* = 0.5 has six potentially hazardous contact routes. Adding an extra occupied bed increases the number of these routes to ten, resulting in a relative increase in risk of 1.667. However, if at the same time the hand washing effectiveness is increased to *ph* = 0.6, then the relative risk is only increased by 1.333. Figure 2 uses Equation 4 to show the relative number of hazardous contact routes that have the potential for transmission following the addition of one, two or three beds to an existing four bed ward. The relative risk is plotted for a range of hand washing compliance values, scaled to a value of *ph* = 0.4, which is considered to be typical (12). The curves in Figure 2 show that the relative number of contacts rises significantly with the number of beds, and that hand washing rates must increase substantially to compensate for this. For example, consider a base-line case of a four bed ward in which hand hygiene effectiveness is 40% (see Figure 2). If two additional beds are added to the ward, the graph indicates that in order to maintain the base-line infection risk (represented by the horizontal line) hand hygiene effectiveness must be in excess of 70%, a difficult task at the best of times, let alone under conditions of increased workload.

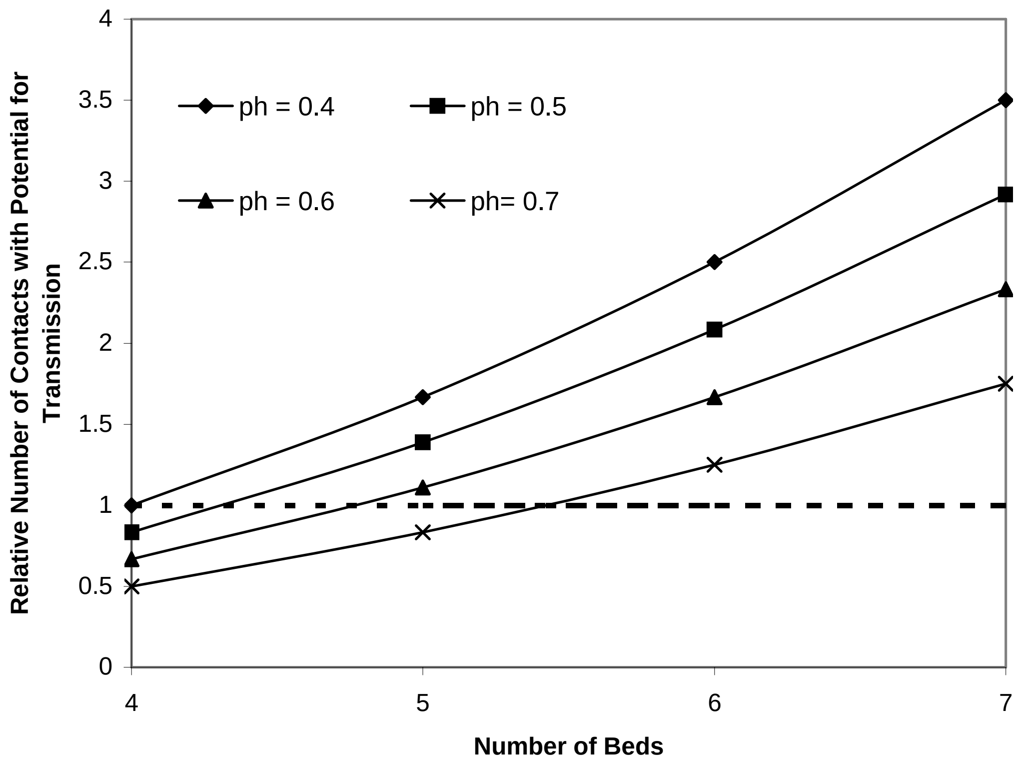


Figure 2: The relative effect (in terms of the number of potential transmission contacts) of adding one, two or three extra beds to an existing four-bed ward, for a range of hand hygiene effectiveness levels (*ph*). (The dotted horizontal line represents the base-line infection risk)

Nurse Cohorting

In a real situation, any increase in the number of beds in a general ward would probably be accompanied by an increase in the number of nursing staff (16). Intuitively this would appear to be the obvious solution to an overcrowding problem, but when the transmissible contacts are considered this may not necessarily be the preferred strategy. Equations 3 and 4 give the number of contacts that potentially result in transmission for each healthcare worker. If for example, in overcrowded conditions two nurses (i.e. the original nurse and a relief nurse) both care for all the patients on the ward then there is potentially double the number of hazardous staff-patient contacts. Rather, in order for improvements to occur, the ward should be divided so that each nurse cares for a certain cohort of patients (i.e. cohort nursing). Provided no contact routes are duplicated, then the increase in staff numbers will lead to a reduction in the number of hazardous contacts, and through a reduction in work pressure will likely result in better hand hygiene compliance and improved housekeeping practices.

If it is assumed that cohort nursing practices are in place such that each member of nursing staff is assigned to a particular patient, or group of patients, then the number of potential harmful contacts can be reduced substantially. This is illustrated by Figure 3, which considers a five bed ward that normally has two members of nursing staff that both care for all the patients, and a hand hygiene effectiveness of 0.4. The results in this figure are calculated using Equation 4 for each healthcare worker, which are then added together to find the total number of contacts. For example, if the ward is divided into groups of two and three patients, respectively, Equation 4 is applied with $\theta = 2$ and with $\theta = 3$ and the results summed. Figure 3 shows that if the nursing duties are divided so that each staff member is ordinarily restricted to specific patients, then the relative number of contact routes and hence the potential for transmission is reduced significantly. In each case both healthcare workers are assumed to have the same hand washing compliance. The results shown in Figure 3 illustrate graphically the importance of cohort nursing, demonstrating that the benefits of good hand hygiene can be greatly undermined by poor cohort practice.

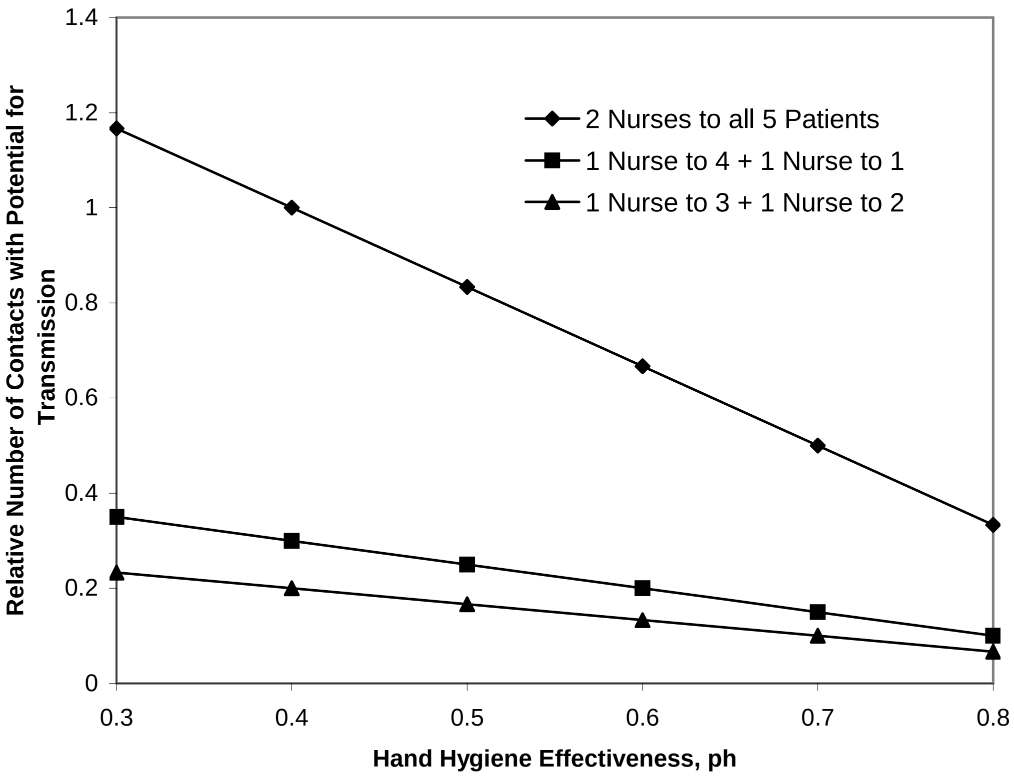


Figure 3: Effect of staffing regime on relative number of contacts with potential for transmission, for a range of hand hygiene effectiveness levels (*ph*).

Discussion

The discussion and analysis presented in sections 3 and 4 demonstrates the important role that nurse cohorting might play in preventing the spread of exogenously-acquired infection. Lack of nurse cohorting may explain why nosocomial outbreaks so often occur in overcrowded or understaffed wards. Indeed, it appears that cohorting, rather than hand hygiene compliance, may be the controlling parameter in many outbreaks. For example, Grundmann *et al*. (9) found exposure to relative staff deficit to be the only factor significantly associated with MRSA transmission, predicting that it would require an additional 12% improvement in adherence to hand hygiene policies to compensate for staff shortages. Given that during this study observed hand hygiene compliance was on average 59%, the investigators concluded that, under conditions of overcrowding and high workload, it would be impossible for the nursing staff to achieve the required additional compliance. From Figure 2 it can be seen that as patient numbers mount, so hand hygiene compliance must increase greatly in order to prevent any additional risk to patients. Although this may appear non-intuitive, it becomes apparent when it is considered that for a four-bedded ward there are 12 direct routes of contact between patients, whereas for a six-bedded ward, this figure rises to 30. Therefore in overcrowded situations, because of the great increase in the number of possible transmission pathways, it becomes very difficult to control infection by hand hygiene measures alone. A more practicable solution would be to employ more staff and adopt a strict cohort nursing strategy, so that the number of transmissible contacts on the ward is reduced – a solution which concurs with Austin et al's finding that "cohorting can provide a highly effective mechanism for reducing transmission" (14).

From the analysis shown in figures 1 and 3, it is clear that maintenance of a cohort nursing policy is of vital importance in preventing the emergence and controlling the spread of outbreaks. In practice, nurses on wards usually work in teams, with each patient assigned to a particular team. In this way, while the number of transmissible contacts between patients on any given team may be high, the number of transmissible contacts between the teams should be low. However, during periods of under-staffing it may be the case that cohort discipline breaks down and this may, in part, explain why outbreaks are so prevalent under these conditions. It should be noted that failure to appreciate the importance of cohort nursing can render, otherwise beneficial, increases in staffing levels useless.

In addition to a decrease in the value of q, during times of understaffing/overcrowding it is much more likely that hand hygiene compliance rates will fall as the work load increases. Pittet et al. (11) in a comprehensive hand hygiene survey, found that compliance fell as workload increased, an observation also made by others (12, 17). Given that there may be 40 opportunities (i.e. requirements) to wash hands per hour of patient care and that in may take as much as 1 minute for a nurse to wash their hands in a basin (11), it is not surprising that during periods of busy patient care nurses find it difficult to find the time to undertake the necessary hand hygiene procedures.

Although it is often assumed that improved hand hygiene compliance will yield ever greater reductions in infection rates (2), this is not necessarily the case. Cooper et al. (18), using a stochastic model, found that a rapid decrease in colonized patient-days was experienced as hand washing frequency increased from zero to 30%. However, they found that very little difference was made to the overall number of colonized patient-days by increasing hand washing compliance above about 40%. Given that hand hygiene compliance rates amongst nurses in publish studies are typical about 40% (12) or greater (9, 11, 17), this suggests that further improvements in infection rates through improved hand hygiene compliance might not be as great as might be anticipated.

The current discussion makes the rather simplistic assumption that every staff/patient interaction is of equal potential importance in contributing to cross-infection. However, in practice, staff/patient interactions fall into different categories, each with a different potential for transmitting an infection. For example, a nurse adjusting a patient's bedding is less likely to transmit an infection than a nurse dressing a wound. There is a need therefore, to develop reliable risk indicators for various clinical activities. If reliable risk factors could be assigned, then it should be possible to develop a methodology for the implementation of a cohorting system in an optimum manner. By eliminating or reducing the most important transmission routes, the maximum possible reduction in the cross-infection rate could be achieved for a given staff/patient ratio. This has the potential to yield very useful information, which could be used to prioritise effort in the fight against infection.

Conclusion

From the analysis above, it can be concluded that nurse cohorting may have an important role to play in the control of exogenously-acquired infection, and that failure to realise this fact may be one reason why rates of so many healthcare-associated infections are so high, e.g. infections associated with methicillin-resistant *Staphylococcus aureus* (19). Although hand washing is important, if the number of transmissible patient-staff-patient contacts is high, as might be the case in an understaffed or overcrowded ward, then hand hygiene measures alone may be insufficient to control nosocomial outbreaks. (2960 words)

References

1. Mertens RAF. Methodologies and results of national surveillance. Baillieres Clinical Infectious Diseases. 1996; 3: 159 – 178.
2. Teare L, Cookson B. Hand hygiene. BMJ. 2001; 323: 411 – 412.
3. Feather A, Stone SP, Wessier A, Boursicot KA, Pratt C. 'Now please wash your hands': the handwashing behaviour of final MBBS candidates. J Hosp Infect. 2000; 45: 62 – 64.
4. Pittet D, et al. Effectiveness of a hospital-wide programme to improve compliance with hand hygiene. Lancet. 2000; 356: 1307 – 1312.
5. Handwashing Liaison Group. Hand washing: A modest measure – with big effects. BMJ. 1999; 318: 686
6. Harbarth S, Sudre P, Dharan S, Cadenas M, Pittet D. Outbreak of Enterobacter cloacae related to understaffing, overcrowding, and poor hygiene practices. Infect Control & Hosp Epid. 1999; 20: 598 – 603.
7. Fridkin SK, Pear SM, Williamson TH, Galgiani JN, Jarvis WR. The role of understaffing in central venous catheter-associated bloodstream infections. Infect Control & Hosp Epid. 1996; 17: 150 – 158.
8. Borg MA. Bed occupancy and overcrowding as determinant factors in the incidence of MRSA infections within general ward settings. J Hosp Infect. 2003; 54: 316 – 318.
9. Grundmann H, Hori S, Winter B, Tami A, Austin DJ. Risk factors for the transmission of methicillin-resistant Staphylococcus aureus in an adult intensive care unit: fitting a model to the data. J Infect Dis. 2002; 185: 481 – 488.

10. Archibald LK, Manning ML, Bell LM, Banerjee S, Jarvis WR. Patient density, nurse-to-patient ratio and nosocomial infection risk in a pediatric cardiac intensive care unit. Pediatr Infect Dis J. 1997; 16: 1045 – 1048.
11. Pittet D, Mourouga P, Perneger TV. Compliance with handwashing in a teaching hospital. Annals Int Med. 1999; 130: 126 – 130.
12. Larson E, Kretzer EK. Compliance with handwashing and barrier precautions. J Hosp Infect. 1995; 30: Suppl. 88 – 106
13. Harbarth S. Nosocomial transmission of antibiotic-resistant microorganisms. Curr Op Infect Dis. 2001; 14: 437 – 442.
14. Austin DJ, Bonten MJ, Weinstein RA, Slaughter S, Anderson RM. Vancomycin-resistant enterococci in intensive-care hospital settings: Transmission dynamics, persistence, and the impact of infection control programs. Proc Nat Acad Sci. 1999; 96: 6908 – 6913.
15. Bonten MJM, Austin DJ, Lipsitch M. Understanding the spread of antibiotic resistant pathogens in hospitals: Mathematical models as tools for control. Clin Infect Dis. 2001; 33: 1739 – 1746.
16. Kibbler CC, Quick A, O'Neill AM. The effect of increased bed numbers on MRSA transmission in acute medical wards. J Hosp Infect. 1998; 39: 213 – 219.
17. Pittet D. Improving compliance with hand hygiene in hospitals. Infect Control Hosp Epidemiol. 2000; 21: 381 – 386
18. Cooper BS, Medley GF, Scott GM. Preliminary analysis of the transmission dynamics of nosocomial infections: stochastic and management effects. J Hosp Infect. 1999; 43: 131 – 147.
19. Department of Health Towards cleaner hospitals and lower rates of infection 2004 (download from http://www.dh.gov.uk/assetRoot/04/08/58/61/04085861.pdf; date last accessed 10/08/2005).