Overcrowding and understaffing in modern health-care systems: key determinants in meticillin-resistant *Staphylococcus aureus* transmission

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Recent decades have seen the global emergence of meticillin-resistant *Staphylococcus aureus* (MRSA), causing substantial health and economic burdens on patients and health-care systems. This epidemic has occurred at the same time that policies promoting higher patient throughput in hospitals have led to many services operating at, or near, full capacity. A result has been limited ability to scale services according to fluctuations in patient admissions and available staff, and hospital overcrowding and understaffing. Overcrowding and understaffing lead to failure of MRSA control programmes via decreased health-care worker hand-hygiene compliance, increased movement of patients and staff between hospital wards, decreased levels of cohorting, and overburdening of screening and isolation facilities. In turn, a high MRSA incidence leads to increased inpatient length of stay and bed blocking, exacerbating overcrowding and leading to a vicious cycle characterised by further infection control failure. Future decision making should use epidemiological and economic evidence to evaluate the effect of systems changes on the incidence of MRSA infection and other adverse events.

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Introduction

Since it was first isolated in the early 1960s in Europe[1] and the USA,[2] meticillin-resistant *Staphylococcus aureus* (MRSA) has spread worldwide. In many countries, recent decades have seen a rapid increase in the incidence and geographical range of MRSA infections[3–8] and related deaths.[9–11] Infection with this organism has become one of the major challenges to modern health-care systems, not least because it is characterised by the ability to spread within and between hospitals and health-care systems.[12,13]

It is widely accepted that MRSA constitutes an additional burden of health-care-acquired infection (HAI) and is not simply a replacement of meticillin-susceptible *S aureus* (MSSA).[14] Although findings have not always been consistent,[15–19] many studies have shown that infections caused by MRSA are associated with higher risk of mortality[20–28] and greater costs to the health-care system[24,29–34] than infections caused by MSSA.

The structure of health-care systems is changing in high-income countries because of a drive towards increased efficiency and economic rationalisation—ie, reorganisation to improve cost-efficiency.[35] In Australia, the health-care system has been characterised by a 40% decrease in public hospital beds per head, a 20% increase in patient throughput between 1982 and 2000, and a 14% increase in the overall number of patients treated between 1995 and 2000.[36] These findings have largely been achieved by an increase in the number and proportion of same-day separations (ie, patients that leave the hospital on the same day as admission). Restructuring in the UK, Canada, the USA, and the Netherlands has also resulted in fewer patients being dealt with as inpatients and more as outpatients, although different scenarios prevail in different countries. For example, bed reductions and hospital closures slowed in the USA during the 1980s and 1990s, actually leading to lower bed occupancy rates.[37] This is by contrast with the UK,[38] where higher patient admission rates together with bed reductions have led to 71% of health trusts exceeding the government target bed occupancy of 82%.[39] In such stressed, high-throughput systems, periodic overcrowding (high bed occupancy rate) and understaffing (low health-care worker to patient ratio) are inevitable because the system has limited capacity to scale according to fluctuations in patient admissions, available resources (such as numbers of staff), and other challenges.

These issues are likely to be intensified by the ageing trend in high-income countries and growth of populations. In Australia, the requirement for hospital beds is predicted to increase by 70–130% by 2050.[40] Concurrently, it is predicted that the age of the health-care workforce in high-income countries will continue to increase, leading to greater staff shortages as retirement rates increase.[41–43] Additionally, fewer people in some high-income countries seem to be choosing nursing as a career, potentially contributing further to the ageing and diminishing size of the health-care workforce.[43] In the USA, these factors have led to an increase in the average age of registered nurses from 37·4 years in 1983 to 41·9 years in 1998 and 46·8 years in 2004.[42,44] Jackson and colleagues[45] have effectively summarised the effect of these findings with their observation: "The nation is facing a nursing shortage that is creating a crisis for quality of health-care and patient safety". The authors were referring to the USA, but this statement equally applies to many high-income countries. Understaffing is both an ongoing and long-term future problem with severe consequences for hospital patients.

In this Review we present evidence for the role of hospital overcrowding and understaffing in the failure of MRSA control programmes. Mechanisms for the interaction between overcrowding, understaffing, and MRSA infection are described and the role of MRSA in

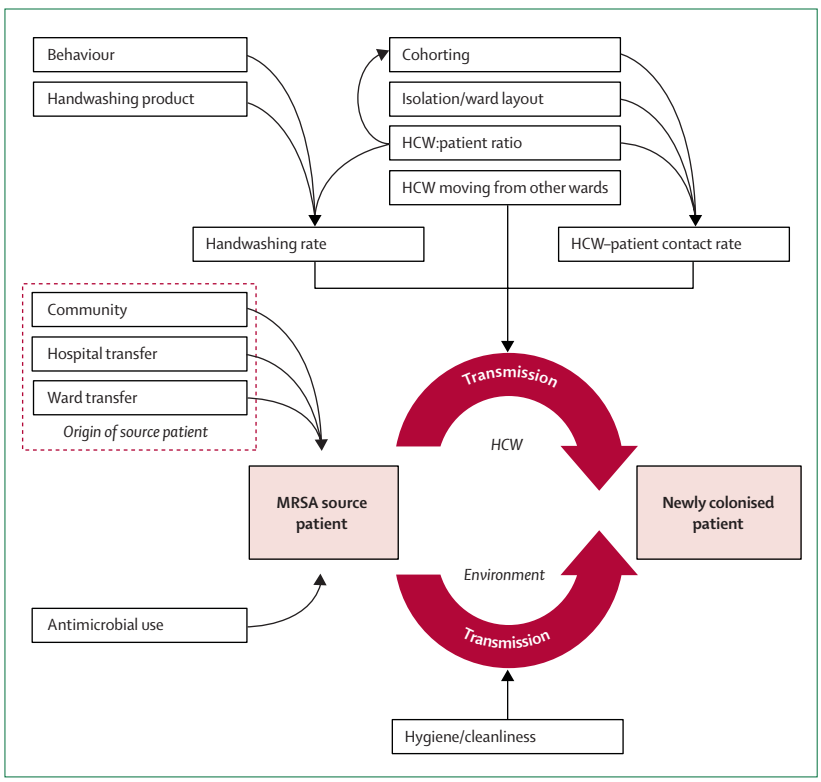

***Figure 1*: Factors linked to transmission of MRSA in hospitals**
HCW=health-care worker.

compounding the problem is outlined, leading to the hypothesis of a vicious cycle. Finally, methods of MRSA control are discussed in this context and more effective decision frameworks are proposed for resource allocation by health policy makers and hospital managers.

Evidence that overcrowding and understaffing in hospitals increase the incidence of HAIs

Many factors are associated with transmission of MRSA in hospitals (figure 1). There is a growing body of evidence that overcrowding of hospitals directly influences many of these transmission factors and impedes MRSA and other HAI control practices. High bed occupancy rates are associated with increased incidence of infection and the occurrence of outbreaks of MRSA[46] and other HAI[47–50] in intensive care units (ICUs) and in general wards.[51] At the hospital or health trust/district level, high occupancy and rapid patient turnover are associated with high incidence of MRSA infection.[52,53]

Transmission of MRSA[54–58] and other HAI-causing organisms[59–61] has been shown to be greater during periods of understaffing, defined by a low health-care worker to patient ratio or other similar indices. Additionally, outbreaks of MRSA infection[46,62] and other HAIs[47–49,63–66] have been reported in intensive or neonatal care units in association with understaffing, and success of MRSA outbreak control has been linked to staff workload.[58,67,68] These studies ranged from untested observations in descriptive epidemiological studies[46,58] to multivariable regression analyses,[55,59] where health-care worker to patient ratio had a significant association with observed infection rates. Hugonnet and colleagues[69] estimated that over a quarter of HAIs could be avoided if the nurse-to-patient ratio was kept to more than 2·2 in ICUs.

The composition or skill-mix of the nursing staff, defined by the ratio of regular nurses to agency, or "pool" or "float" staff (ie, staff not normally assigned to a particular hospital unit, but who are moved between units or hospitals in response to staffing requirements), or the proportion of experienced staff, have also been associated with incidence of HAI.[60,70,71] A common strategy to decrease health-care system costs has been to replace registered nurses with nursing assistants, and to reduce the proportion of full-time staff.[35,37,72] Fridkin[63] and Stegenga[66] and their colleagues noted that cost savings in hospitals achieved by workforce re-engineering might be offset by increased costs arising because of the more frequent occurrence of HAIs and other adverse events.

Mechanisms by which overcrowding and understaffing increase incidence of MRSA infection

Handwashing by health-care workers between individual patient contacts is an important measure for reducing transmission of MRSA and other HAI-causing organisms. Many studies have shown compliance with hand-hygiene practices to be low, with physicians being less compliant than nurses.[73–77] Furthermore, the frequency of handwashing decreases as the rate of indications for handwashing increases.[73–78] Compliance falls further during periods of understaffing and high workload.[55,74,76,79–81]

Anecdotal reports have suggested a link between outbreaks of MRSA[62,82] and other HAIs,[47,49] understaffing, and associated poor health-care worker hand-hygiene compliance. Raboud[83] and McBryde[84] and their co-workers found, using simulation approaches, increasing hand-hygiene compliance to be the most effective method for reducing MRSA transmission for a general medical ward and ICU, respectively.

The association between hand-hygiene compliance and workload is not a simple function of the time available to properly undertake hand-hygiene practices. More convenient placement of sinks during conversion of an open-plan ICU to private isolation units did not improve rates of handwashing.[85] Lack of health-care worker education and skin irritation caused by handwashing are additional impediments to hand-hygiene compliance.[77,80,86] Investigations have shown that training and other interventions (eg, alcohol-based handrubs) specifically aimed at increasing health-care worker compliance with hand-hygiene procedures have a role in improving rates of handwashing,[73,81,87] and reducing incidence of MRSA and other HAIs.[86,88–91] However, hand-hygiene compliance

studies are complicated by the Hawthorne effect—ie, study participants might change their behaviour in response to being observed. Additionally, although Pittet and colleagues[90] reported improved compliance at a range of activity levels (based on the number of indications for handwashing per hour) following a hand-hygiene promotion programme, the long-term efficacy of such interventions under conditions of overcrowding and understaffing is yet to be investigated.

Cohorting of patients (restricting contact with patients to an assigned health-care worker), where the level of cohorting is measured by the percentage of patient contacts for a health-care worker that involve the same patient as the previous contact, is another important method of reducing MRSA transmission. Grundmann and colleagues[55] found that increasing hand-hygiene compliance or cohorting levels by 12% (from baseline values of 52% and 46%, respectively) would result in elimination of MRSA transmission in an adult ICU. Overcrowding and understaffing are associated with higher nurse–patient interaction rates and reduced levels of cohorting.[74] Beggs and co-workers[92] used a mathematical model to show the interactions between cohorting level, rate of hand-hygiene compliance, and MRSA transmission potential. The investigators concluded that the effectiveness of hand-hygiene measures are impeded by overcrowding and they are insufficient to control MRSA outbreaks in overcrowded wards with high rates of health-care worker to patient contact.

Increasing the number of beds in a fixed-area ward as an attempt to alleviate pressure on bed use has been shown to actually increase MRSA transmission and cross-infection.[93] Additional beds result in an increase in possible contact routes and, without a substantial increase in hand-hygiene compliance, greater transmission of MRSA.[92] Screening and physical isolation of patients infected with, colonised by, or potentially exposed to, MRSA are other important control measures. Provision of more single-patient rooms in hospitals also reduces MRSA transmission.[94] Overcrowding can lead to overburdening of isolation facilities, impeding the effectiveness of these approaches.[95]

Bignardi and Askew[82] suggested that high incidence of MRSA infection is symptomatic of "organisational fatigue", which relates to overburdening of staff and facilities during periods of high bed occupancy and workload. Factors including staff turnover rate, staff burn-out and associated rates of absenteeism, and degree of management emphasis on staff satisfaction—all associated with understaffing—have simultaneously been associated with incidence of HAI,[96,97] suggesting an additional emotional or psychological component in quality of care. Overcrowding leads to more frequent movement of patients and staff between hospital areas, increasing the transmission potential of MRSA, and increased intermixing of specialties within wards, also a factor that contributes to higher MRSA infection risk.[98]

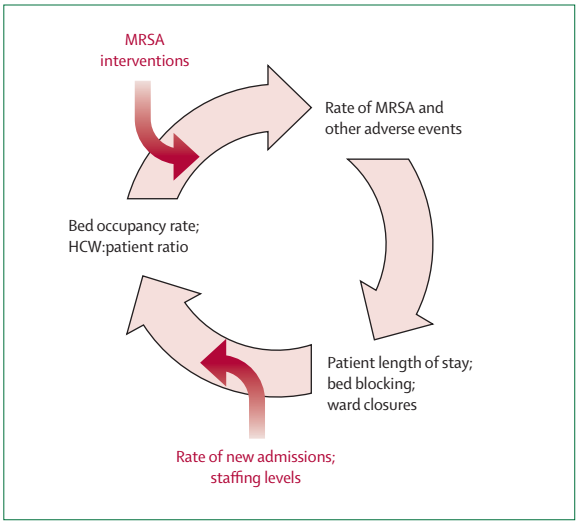

***Figure 2*: Overcrowding and understaffing: a vicious cycle**
Overcrowding (high bed occupancy rate) and understaffing (low health-care worker to patient ratio) increase MRSA infection rates, which in turn leads to increased patient length of stay, bed blocking, and ward closure, thus exacerbating overcrowding and understaffing. HCW=health-care worker.

Other mechanisms for increased MRSA transmission in higher bed occupancy settings might include greater bacterial contamination of inanimate surfaces because of higher patient density and less rigorous decontamination practices (which may occur during HAI outbreaks)[62] and, possibly, increased airborne dispersal.[99]

Evidence and mechanisms for MRSA infection exacerbating overcrowding and understaffing

There is increasing evidence that rising incidence of MRSA infection and increasing numbers of outbreaks within health-care systems can exacerbate conditions of overcrowding and understaffing within hospitals. We argue that this contributes to a vicious cycle, where the occurrence of MRSA makes it more difficult to implement effective infection control strategies, leading to subsequent breakdowns in infection control and further increases in the incidence of MRSA (figure 2).

MRSA infection affects bed use because it is associated with longer patient length of stay in hospital. Studies have consistently found higher length of hospital stay associated with MRSA than MSSA bloodstream infections (a 2–18 day increase compared with MSSA).[29,30,32,34,100] Similar patterns have been shown for MRSA ventilator-associated pneumonias[101] and surgical site infections[24] relative to MSSA. The wide range of values is testament to the various forms of bias inherent in all these studies,[102,103] and although it is generally agreed that MRSA generates some increase to patient length of hospital stay,[102] a precise figure is not known. Extensions to length of stay might result from less effective treatment, underlying patient severity of illness associated with resistant (compared with susceptible) organism infections, logistical factors such as the need to postpone

surgical procedures,[104] or provision of resources such as wards with appropriate isolation facilities.[101]

Extended length of hospital stay in infected individuals makes hospital beds unavailable for new admissions. This puts pressure on the capacity of the affected ward and wards to which new patients are diverted. In situations where incidence of MRSA exceeds the capacity of isolation facilities, multi-bed rooms might be used for isolation, preventing the use of both the occupied and unoccupied beds,[105,106] a phenomenon termed "bed blocking".[107] A blocked bed represents an opportunity cost (ie, a lost opportunity to provide services to another patient), which in public health care can be difficult to quantify in economic terms. With average duration of isolation reported at between 20 and 36 days,[108,109] beds can be blocked for extended periods. Over a 4-year period Cooper and colleagues[106] reported a loss of 0·35% of total available bed days due to MRSA, with 40% of these caused by bed blocking, whereas Herr and co-workers[107] calculated more than 80% of the excess costs associated with MRSA control were caused by blocked beds.

Large outbreaks of epidemic MRSA, or those that cannot be brought under control, might result in ward closure, the consequences of which can be seen as an extreme example of bed blocking.[14] The effect of extended length of hospital stay, bed blocking, and ward closures in delaying admission to the affected ward can resonate through the hospital system resulting in emergency department overcrowding,[104,106] postponement of elective surgery,[110] cancellation of elective admissions,[104,106,110] and overcrowding on related wards.[58] In resource-limited situations, high incidence of MRSA infection can overburden isolation facilities, leading to a vicious cycle where isolation practices are unable to cope with (and prevent) new MRSA infections.[95] Cepeda and colleagues[111] showed that isolation practices were ineffective in an MRSA endemic setting. Conversely, Bootsma and co-workers[112] showed that where adequate facilities are available, rigorous MRSA control measures (involving isolation and screening) can reduce incidence of MRSA infection and eventually ease the burden on isolation facilities, subsequently increasing the efficacy of isolation as a control measure.

MRSA can compound problems of understaffing in hospitals through its effect on staff workloads and staff availability. Nursing workloads for those involved in the management of HAI have been shown to rise as a result of an increase in both patient length of stay and severity of illness resulting from infection[113,114] (although the latter is difficult to differentiate from the underlying severity of illness that actually contributed to the infection). Workloads for nurses caring for patients with infections caused by multiresistant organisms are increased because of the increase in infection control[113–116] and therapeutic[109,116,117] activities that these infections require; however, such situations are seldom accompanied by increases in staffing levels, and thus represent an additional work burden on nursing staff.[115]

MRSA contributes directly to staffing deficits when health-care workers are excluded from work as a result of colonisation, detected via routine or outbreak screening.[110,118–120] MRSA infection increases not only the workload of nursing staff, but also the workload of infection control practitioners,[115] who have a reduced capacity to undertake generic infection control activities in the face of a high MRSA burden in the hospital,[14,58,104,121] and of laboratory staff, who undertake MRSA screening of admitted patients.[109]

Improved decision making for MRSA control

Not all countries have seen the development of a widespread MRSA epidemic—eg, the incidence of MRSA infection remains low in the Netherlands and in Scandinavian countries.[122,123] Successful prevention of epidemic MRSA seems to have been achieved in these countries by implementing rigorous, but cost-effective measures at the national level[110] that might also be applicable for reducing incidence of MRSA infection in high-endemicity countries.[112] This postulation is supported by evidence that in some countries, such as the UK and Australia, there has been a stabilisation, or even a decrease in the incidence of MRSA infection following widespread implementation of MRSA control measures.[124,125] Although the burden of HAI is enormous, it has been estimated that 15–32%[126,127] of cases can be prevented and economic losses reduced.[128] At the level of the hospital, rigorous interventions including screening of new admissions and isolation of high-risk patients are effective in reducing incidence of MRSA[112,129,130] and lead to cost savings, both in endemic[109,117,131,132] and epidemic scenarios.[97,133,134] Less intensive interventions based on isolation[135] or use of more effective hand hygiene and disinfection products,[136,137] have also proved successful.

More work needs to be done to determine the most cost-effective MRSA control measure(s) for a given situation. Evidence for selecting the best measure could be based on intervention trials or epidemiological modelling studies, together with an economic assessment of the control alternatives.[138,139] We believe an intervention trial approach has important disadvantages compared with the modelling approach in that patients would be denied access to interventions that are known to be effective; individuals cannot be randomised to the intervention and so a cluster design (randomising hospitals or wards) would be required, substantially increasing the required sample size and related costs; many risk-reducing strategies exist, so a thorough trial would need multiple arms; and outcomes such as the costs and health effects of interventions would occur for many years into the future and so would only be captured by a very long follow-up.

We also suggest that comprehensive assessments of MRSA control options consider the root causes of overcrowding and understaffing. Cameron[140] recently outlined a number of methods for tackling hospital

Search strategy and selection criteria

Data for this Review were obtained by searches of PubMed and Medline and from additional searches of the reference lists of retrieved articles. Search terms included "MRSA", "overcrowding", "understaffing", "overwork", "overburden", "bed occupancy", "patient flow", "patient stay", and "length of stay". We did not review studies of community-acquired MRSA. Abstracts of English, French, and Spanish language papers were read and considered for inclusion, although only English language papers were selected for the final review. No date restrictions were placed on these searches.

overcrowding, including practices aimed at reducing hospital demand and practices aimed at optimising the capacity of hospitals to provide health-care services. Strategies to reduce hospital demand included diverting patients from hospitals to community services, instigating public debate on essential versus desirable health-care services with a view to limiting and prioritising freely available public health care, and implementation of improved disease prevention programmes (such as interventions for MRSA). Strategies to optimise health-care services provided by hospitals included implementing more efficient health-care delivery through improved infrastructure and health-care workforce reform, better balancing of elective and emergency admissions, better management of patient discharge to appropriate facilities, and adequate provision of hospital beds.

Conclusions

The drive towards greater efficiency by reducing the number of hospital beds and increasing patient throughput has led to highly stressed health-care systems with unwelcome side-effects. Overcrowding and understaffing have had a negative effect on patient safety and quality of care, evidenced by the flourishing of health-care-acquired MRSA infections in many countries, despite intense efforts to control and prevent these infections occurring. The economic benefits of downsizing health-care systems are likely to have been offset by the increased burden of adverse events, such as MRSA infection, leading to a false economy. There is an urgent need for detailed study of the relative effects of acute short-term and chronic long-term resource constraints on the dynamics of MRSA infection and a concurrent requirement for developing resource allocation strategies that minimise MRSA transmission without compromising the quality and level of patient care. We suggest that future control programme evaluations explicitly consider available infrastructure and staffing resources so that recommendations arising from the evaluation can be applied to real-world settings. We also advocate that proponents of change to health-care systems give more attention to patient safety and burden of adverse events, together with associated costs.

Conflicts of interest

We declare that we have no conflicts of interest.

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