Underestimation of Staphylococcus aureus (MRSA and MSSA) carriage associated with standard culturing techniques: one third of carriers missed.

Citation for published version:

Digital Object Identifier (DOI):
10.1302/2046-3758.71.BJR-2017-0175.R1

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Publisher’s PDF, also known as Version of record

Published In:
Bone & Joint Research

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INFECTION

Underestimation of Staphylococcus aureus (MRSA and MSSA) carriage associated with standard culturing techniques

ONE THIRD OF CARRIERS MISSED


University of Edinburgh, Edinburgh, United Kingdom

Objectives

Nasal carriers of Staphylococcus (S.) aureus (MRSA and MSSA) have an increased risk for healthcare-associated infections. There are currently limited national screening policies for the detection of S. aureus despite the World Health Organization’s recommendations. This study aimed to evaluate the diagnostic performance of molecular and culture techniques in S. aureus screening, determine the cause of any discrepancy between the diagnostic techniques, and model the potential effect of different diagnostic techniques on S. aureus detection in orthopaedic patients.

Methods

Paired nasal swabs for polymerase chain reaction (PCR) assay and culture of S. aureus were collected from a study population of 273 orthopaedic outpatients due to undergo joint arthroplasty surgery.

Results

The prevalence of MSSA nasal colonization was found to be between 22.4% to 35.6%. The current standard direct culturing methods for detecting S. aureus significantly underestimated the prevalence (p = 0.005), failing to identify its presence in approximately one-third of patients undergoing joint arthroplasty surgery.

Conclusion

Modelling these results to national surveillance data, it was estimated that approximately 5000 to 8000 S. aureus surgical site infections could be prevented, and approximately $140 million to $950 million (approximately £110 million to £760 million) saved in treatment costs annually in the United States and United Kingdom combined, by using alternative diagnostic methods to direct culture in preoperative S. aureus screening and eradication programmes.

Cite this article: Bone Joint Res 2018;7:79–84.

Keywords: Surgical site infection, Staphylococcus aureus, Periprosthetic joint infection

Article focus

- This study aimed to evaluate the diagnostic performance of molecular and culture techniques in S. aureus screening, determine the cause of any discrepancy between the diagnostic techniques; and model the potential effect of different diagnostic techniques on S. aureus detection in orthopaedic patients.
- Polymerase chain reaction or preplating broth enrichment of swabs for culture can significantly improve nasal MSSA detection.
- Use of optimal techniques could prevent up to 8000 MSSA SSIs per annum in the United States and United Kingdom combined.

Strengths and limitations

- This study provides the first evaluation of the effect that different diagnostic methods have on the prevalence of nasal MSSA colonization in an elective orthopaedic population.
The main limitation of this study was that PCR-negative samples were not analyzed in the cohort of samples undergoing enrichment, preventing a complete evaluation of the enrichment technique.

Introduction

Healthcare-associated infection is a significant clinical issue, particularly surgical site infection (SSI). SSI is widely used as a quality indicator in healthcare systems and reporting is mandatory in many settings, notably by Surgical Site Infection Surveillance Service (SSISS) from Public Health England and through the Center for Disease Control (CDC) in the United States. Orthopaedic surgery is a primary focus of SSI surveillance, given the high rates of implant surgery and the major impact that SSI can have on patients’ health-related quality of life, function, healthcare costs, and medicolegal implications.

The reported SSI incidence for knee and hip arthroplasties undertaken in developed nations has been estimated to be between 0.5% and 2%, based on inpatient, readmission episodes, and the number of revision procedures that are performed. However, even national surveillance estimates may under-report the true incidence. The available data suggests that downward trends have levelled off, although rates for knee surgery may be rising. This could reflect a changing prevalence of risk factors for infection, such as revision surgery, longer operation times, higher BMI, and greater patient comorbidity. Gram-positive bacteria have been reported as accounting for 46% of all SSIs, in all branches of surgery. For hip and knee arthroplasty, among monomicrobial infections (which account for around 75% of all patients), between 30% and 38% were methicillin-sensitive Staphylococcus (S.) aureus (MSSA), between 4% and 5% were methicillin-resistant S. aureus (MRSA), and between 25% and 28% were coagulase negative staphylococci. In polymicrobial cases Gram-positive bacteria have been implicated in around 70% and 80% of patients. For orthopaedic surgery, Gram-positive organisms account for the majority of SSIs.

High-level nasal carriers of MSSA have a risk of healthcare-associated MSSA infection that is three to six times the risk compared with noncarriers and low-level carriers and is similar in both surgical and non-surgical hospitalized patients. It is also known that more than 80% of healthcare-associated S. aureus infections are endogenous, implying that acquisition is from sites on the patient’s own body. The association between nasal carriage of S. aureus, specifically MRSA, and SSI has been demonstrated in a systematic review and confirmed in recent cohort studies.

A pan-European study reported that 21.6% of healthy European residents carry S. aureus in their nose, with the rate in the United Kingdom being 25%, although there was wide variation between countries. A recent retrospective part cohort United Kingdom-based study among patients undergoing elective orthopaedic surgery reported a threefold reduction in MSSA-associated SSI, using a routine preoperative screening and decolonization programme. In contrast to MSSA, MRSA prevalence in healthy community individuals is estimated to be <2%. Screening of patients presenting for surgery or admitted to hospital areas with strong risk factors for MRSA, such as intensive care units (ICUs), dialysis units, and elderly care areas, is widely practised in healthcare systems. The National Screening policy for MRSA in the United Kingdom recommends the use of two swabs (a nasal swab plus a perineal or throat swab) cultured directly or following pre-enrichment onto chromogenic MRSA-selective media. As primary screening media, the American Society for Microbiology recommends salt-containing tryptone soya broth (TSB) in conjunction with a blood agar plate and mannitol-salt agar (MSA) containing 4 µg of oxacillin per millilitre. There are currently no national screening policies for MSSA in the United Kingdom or United States prior to orthopaedic surgery, despite the recent recommendations from the World Health Organization.

The aims of this study were to evaluate the diagnostic performance of molecular and culture techniques in S. aureus screening using paired nasal samples, to determine the cause of any discrepancy between the diagnostic techniques and to model the potential effect of different diagnostic techniques on S. aureus detection in orthopaedic patients.

Materials and Methods

Nasal swabs for polymerase chain reaction (PCR) assay and culture of S. aureus were collected from a study population of 273 orthopaedic outpatients due to undergo joint arthroplasty surgery at a university teaching hospital (Royal Infirmary Edinburgh) between October 2015 and September 2016. The study protocol was reviewed and approved by the regional ethics committee (REC 15/SS/0091). Patients presenting for assessment prior to orthopaedic implant surgery were prospectively enrolled and provided written consent. All specimens were collected by trained research nurses and were processed within three hours of collection. Patient data was anonymized, processed, and stored in accordance with established guidelines.

The Xpert S. aureus Nasal Complete Assay (Cepheid, Sunnyvale, California) was carried out according to the manufacturer’s instructions. Swab tips (Sample Collection device, Cepheid) were placed in elution buffer, vortexed, and added to a test cartridge, which was loaded into the GeneXpert (Cepheid) Instrument. Primers and probes are included to detect S. aureus (staphylococcal protein A, spa) as well as two markers of methicillin resistance (the methicillin resistance gene mecA and the staphylococcal...
Table 1. Complete results of Xpert PCR assay, direct culture, and pre-enrichment culture for Staphylococcus aureus nasal screening

<table>
<thead>
<tr>
<th>Assay</th>
<th>Positive, n (%)</th>
<th>Negative, n (%)</th>
<th>Result not available</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MSSA MRSA Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xpert PCR assay (n=273)</td>
<td>94 (33.6) 6 (2.3) 100 (37.9)</td>
<td>164 (62.1)</td>
<td>9*</td>
</tr>
<tr>
<td>Direct culture (n=181)</td>
<td>37 (22.4) 2 (1.2) 39 (23.6)</td>
<td>126 (76.4)</td>
<td>16†</td>
</tr>
<tr>
<td>Pre-enrichment culture (n=92)</td>
<td>28 (80.0) 3 (8.6) 31 (88.6)</td>
<td>4 (11.4)</td>
<td>57‡</td>
</tr>
</tbody>
</table>

*Invalid result by Xpert PCR
†Culture not performed in line with study protocol
‡Enrichment not performed on Xpert PCR negative samples
MSSA, methicillin-sensitive Staphylococcus aureus; MRSA, methicillin-resistant Staphylococcus aureus; PCR, polymerase chain reaction

Using data reported in the literature, the risk of S. aureus SSI in patients with known nasal colonization, the risk reduction associated with a preoperative MSSA screening and eradication, and annual rates of joint arthroplasty surgery were estimated. These estimates were combined with the diagnostic performance characteristics from the paired nasal samples to model the effect discrepancies in diagnostic performance would have on national MSSA SSI incidence.

**Results**

In the 273 patients undergoing nasal screening, the median age was 68 years (interquartile range (IQR) 61 to 75), 176 of whom were female (64.5%). Of these patients, 239 (87.6%) were due to undergo primary hip or knee arthroplasty. From the initial 273 paired samples, a total of 16 sample pairs (5.9%) were excluded due to Xpert assay failure (n=9, 3.3%) or failure to perform culture as per study protocol (n=7, 2.6%), leaving 257 paired samples available for analysis. The results of the PCR and culture assays are shown in Table I. The Xpert PCR assay found 37.9% of samples to be positive (95% confidence interval (CI) 32.0 to 44.0), with 35.6% MSSA (95% CI 29.8 to 41.7) and 2.3% MRSA (95% CI 0.8 to 4.9). Direct culture found 23.6% of samples to be positive (95% CI 17.4 to 30.9), with 22.4% (95% CI 16.3 to 29.6) and 1.2% (95% CI 0.1 to 4.3) confirmed as MSSA and MRSA, respectively. Pre-enriched culture found 33.7% of samples to be positive (95% CI 24.2 to 44.3), with 30.4% MSSA (95% CI 21.3 to 40.9) and 4.3% MRSA (95% CI 1.2 to 10.8).

A summary of the performance characteristics taken from the 58 paired samples that underwent both PCR assays and either direct or pre-enriched culture is shown in Table I. Analysis of the data suggested that the cause of the discrepancy was due to a lack of sensitivity associated with direct culture.

The absolute difference in estimated prevalence of nasal MSSA colonization between the PCR assay and direct culture was 13.1% (95% CI 4.6 to 21.8), which was statistically significant (p=0.005). Exclusive use of direct culture would estimate the MSSA prevalence 8.0% (95% CI 3.3 to 19.4) lower than pre-enriched culture, which was not statistically significant (p=0.167).
It is estimated that almost 120 000 primary joint arthroplasties are performed annually in the United States and United Kingdom combined (Table II).²⁷⁻²⁹ If direct culture were to be used exclusively over PCR or pre-enriched culture in the United States, approximately 96 200 to 156 000 such patients with nasal MSSA colonization would be missed (Table II). It has previously been reported that nasal S. aureus colonization has an absolute risk of S. aureus SSI of 7.7% in elective orthopaedic patients (95% CI 5.4 to 10.8).³⁰ S. aureus screening and eradication programmes prior to elective orthopaedic surgery have a reported relative risk reduction of 66.4% (95% CI 45.8 to 87.0) for the prevention of S. aureus SSI.¹⁸⁻³⁰⁻³⁴ According to economic estimates in the United States, the hospital treatment costs for an individual patient with prosthetic joint infection (PJI) range from $30 000 to $120 000.³⁵⁻³⁷ Estimates in the United Kingdom for total hospital care costs per case are similar to that in the United States (between £20 000 and £100 000).³⁸⁻³⁹ Therefore, 4860 to 7900 S. aureus SSIs could potentially be prevented, and approximately $140 million to $950 million (approximately £110 million to £760 million) saved in treatment costs in the United Kingdom and the United States combined, by using PCR or enrichment culture, rather than direct culture in S. aureus screening programmes (Table II).

Discussion
This study provides the first evaluation of the effect that different diagnostic methods have on the prevalence of nasal MSSA colonization in a United Kingdom elective orthopaedic population. Using a combination of published data and the results of this study, the likely effect on S. aureus SSI incidence, if direct culture methods are adopted nationally, has been modelled. The MSSA prevalence in this study was estimated to be between 22.4% and 35.6%, depending on the diagnostic method, broadly in line with previous studies.¹⁸⁻⁴³ Meenan et al." reported an S. aureus prevalence rate of 41.7% in a cohort of 204 obstetrics and gynaecology patients in Ireland. The prevalence of MSSA and MRSA was 40.7% and 1.0%, respectively. Nadimpalli et al." found out of 210 workers exposed to livestock production facilities in the USA, 83 (40%) had nasal S. aureus colonization. Van Vugt et al." reported a nasal S. aureus colonization rate of 40.5% amongst 366 surgeons and surgical trainees, compared with a 30.8% prevalence out of 950 in a healthy non-hospitalized control group in The Netherlands. A recent United Kingdom-wide study of elective orthopaedics patients reported an MSSA prevalence of 29% using direct culturing techniques alone (89 MSSA positive patients of 307 elective patients screened).¹⁸ In a review of longitudinal studies Wertheim et al." reported that “a mean of about 20% (12% to 30%) of individuals are persistent S. aureus nasal carriers, approximately a mean of 30% are intermittent carriers (16% to 70%) and about 50% (16% to 69%) are non-carriers”. It is likely that the S. aureus carriers in this study represent a mix of persistent and intermittent carriers who have been in contact with health care facilities, which may explain the higher prevalence rate.

The performance characteristics of the PCR assay and pre-enriched culture were found to be similar in this study. Both techniques were found to be more sensitive than direct culture in the detection of nasal MSSA. There was increased cost for consumables and processing of the PCR assay (£28/$35) compared with pre-enriched culture (£14/$18) and direct culture (£13/$16). Previous studies have reported mixed performance characteristics when comparing PCR to culture techniques. Andriesse et al." reported a lower sensitivity for two PCR assays (82.0% and 85.6%) in comparison to a pre-enriched semi-quantitative culture technique (98.2%) in the detection of MSSA nasal colonization when using pre-enriched conventional culture as a benchmark. Wassenberg et al." performed an evaluation of the GeneOhm MRSA (Becton Dickinson Diagnostics, San Diego, California) and Gene-Xpert MRSA PCR assays, as well as direct culture onto a selective, chromogenic agar (MRSA-ID, bioMérieux) using direct conventional culture as the reference in the

<table>
<thead>
<tr>
<th>Approx. no. of PJAs per annum</th>
<th>No. of patients with nasal MSSA colonization potentially missed</th>
<th>No. of preventable S. aureus SSIs</th>
<th>Approx. treatment costs potentially saved</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>1 000 000</td>
<td>80 000 to 130 000</td>
<td>$120 million to $790 million</td>
</tr>
<tr>
<td>England, Wales, and Northern Ireland</td>
<td>182 000</td>
<td>15 000 to 24 000</td>
<td>$20 million to $150 million</td>
</tr>
<tr>
<td>Scotland</td>
<td>16 000</td>
<td>1200 to 2000</td>
<td>$1.5 million to $12.5 million</td>
</tr>
<tr>
<td>Total</td>
<td>1 198 000</td>
<td>96 200 to 156 000</td>
<td>$141.5 million to $952.5 million</td>
</tr>
</tbody>
</table>

*The approximate number of patients with nasal MSSA colonization who would be missed if direct culture were to be used exclusively over polymerase chain reaction or pre-enriched culture.

†The number of surgical site infections that could potentially be prevented if polymerase chain reaction or pre-enriched culture were used, rather than direct culture.

‡The approximate amount that could be saved in treatment costs if polymerase chain reaction or pre-enriched culture were used, rather than direct culture, in Staphylococcus aureus screening programmes.

§Converted from GBP (£16 million to £120 million) to USD at a rate of £1 = $1.25 (the mean GBP to USD rate for February 2017, rounded to the nearest five cents).

¶Converted from GBP (£1.2 million to £10 million) to USD at a rate of £1 = $1.25 (the mean GBP to USD rate for February 2017, rounded to the nearest five cents).

The approximate amount that could be saved in treatment costs if polymerase chain reaction or pre-enriched culture were used, rather than direct culture, in Staphylococcus aureus screening programmes.
detection of MRSA in non-critical care hospital admissions. The PCR assays were found to have 85.2% and 75.0% sensitivity, and 96.5% and 94.5% specificity, respectively. Direct culture on chromogenic agar had an 85.7% and 96.6% sensitivity and specificity, respectively. A similar study was repeated by the same group in Dutch ICU admissions, with higher sensitivity levels (100%) and similar specificity levels (95.7%) associated with the GeneXpert MRSA assay. No MRSA were detected using the culture technique in this Dutch ICU study and thus the sensitivity could not be calculated. The specificity of culture using chromogenic agar was 93.3%. In contrast, Bebko et al reported a higher detection level with PCR compared with direct culture when they evaluated the diagnostic performance of the GeneXpert assay in patients prior to undergoing orthopaedic implant surgery. They reported that PCR assay had a 100% sensitivity and 77.1% specificity when used for detection of nasal MSSA, when using culture as the benchmark.

Previous comparisons between pre-enrichment and direct culture for the recovery of MSSA from clinical samples have been reported. McAllister et al found that enrichment of swabs using TSB increased sensitivity for Staphylococcus aureus by 13% compared with direct plating when using MSA culture medium in 600 HIV-positive outpatients. Meenan et al reported a 16% increase in sensitivity with enrichment, using brain-heart infusion, when compared to direct plating onto CBA. In the same study, enrichment of swabs increased sensitivity for Staphylococcus aureus by 31% compared with direct plating onto a selective chromogenic agar (bioMérieux S. aureus ID medium agar). In our study, enrichment increased the sensitivity for Staphylococcus aureus by 21% compared with direct plating, a greater increase than reported by McAllister et al in HIV positive patients. The sensitivity for the detection of nasal Staphylococcus aureus associated with enrichment of swabs in our study was similar to that reported by Nadimpalli et al. They found enrichment (Mueller-Hinton broth, 6.5% NaCl) of nasal swabs was associated with an 80.7% and 90.4% sensitivity for Staphylococcus aureus when using Baird-Parker agar and a chromogenic agar, respectively. They also found reported high inter-observer agreement, kappa coefficient 0.69 (95%CI 0.59 to 0.80), between the two-culture media. Despite the favourable performance characteristics of both PCR and enrichment culture, the barriers to universal uptake have been cost-effectiveness and increased processing time, respectively.

The main limitation of this study was that PCR-negative samples were not analyzed in the cohort of samples undergoing enrichment. This prevented a complete evaluation, with receiver operating characteristic analysis, of the enrichment technique. The decision not to analyze these samples was based on the high specificity (98%) demonstrated by the direct plating technique. A further limitation was that we compared culture with a test that is not a universally accepted gold standard (i.e. combined PCR assays). PCR detects nucleic acid and does not distinguish between dead or live bacteria; as only viable bacteria are detected by culture, it is possible the sensitivities we report for culture may be falsely low. However, we believe that this is not the case as we show enrichment provides a similar sensitivity to PCR, suggesting that the false negatives with direct culture are due to missed low-level positive samples. Data were derived from the literature during the modelling process, which made it necessary to use assumptions that may affect the validity of the estimates produced.

In summary, we found the prevalence of MSSA nasal colonization was found to be between 22% and 36%. The use of PCR assays or pre-plating enrichment of swabs in TSB significantly improves nasal MSSA detection levels, which is relevant to both future research and clinical practice. These results should be considered when interpreting prevalence studies, when evaluating intervention studies, and in the development of future screening and decolonization strategies.

References

surgery: the role of nasal contamination. A systematic literature review and meta-


Acknowledgements

The authors would like to thank the Orthopaedic Department Research Nurses, Microbiology Biomedical Scientists, and Edinburgh Clinical Trials Unit for the support received during the data collection and processing.

Funding Statement

This research was supported by the Royal College of Surgeons Edinburgh (Joint RCSEd/Cutner Research fellowship awarded to S. T. J. Tsang), Leonardo (Selox Medical) (Research grant awarded to T. S. Walsh), and Arthritis Research UK (Research grant awarded to A. H. R. W. Simpson).

Author Contribution

S. T. J. Tsang: Study conception and design, Collecting and analyzing the data, Writing and editing the manuscript.

M. P. McHugh: Collecting and analyzing the data, Writing and editing the manuscript.

D. Guerendiain: Collecting and analyzing the data, Editing the manuscript.

P. J. Gwynne: Analyzing the data, Writing and editing the manuscript.

J. Boyd: Study conception and design, Collecting and analyzing the data, Writing and editing the manuscript.

A. H. R. W. Simpson: Study conception and design, data analysis, writing and editing of manuscript.

T. S. Walsh: Study conception and design, Analyzing the data, Writing and editing the manuscript.

I. F. Laurenson: Study conception and design, Analyzing the data, Writing and editing the manuscript.

K. E. Templeton: Study conception and design, Analyzing the data, Writing and editing the manuscript.

Ethical Statement

This study was approved by the South-east Scotland Research Ethics Committee (reference 15/SS/0091) and witnessed consent was obtained from all enrolled patients.

Conflicts of Interest Statement

The authors declare that there are no conflicts of interest.