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Risk factors for persistent Staphylococcus aureus nasal carriage in the community

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Abstract

Staphylococcus aureus is a major human pathogen and commensal of the nose and other body sites. S. aureus colonisation (carriage) increases the risk of infection, so identifying carriers is central to infection control; however, few studies have combined robust methods with sufficient statistical power to determine the risk factors for carriage. We recruited over 22,000 adults into the CARRIAGE cohort study, who each returned self-taken nasal swabs and a questionnaire weekly for three weeks. We show that in a multivariable analysis with correction for multiple testing that the only factors significantly associated with persistent S. aureus carriage were younger age (with carriage rates declining after 60), male sex, higher BMI, chronic skin conditions, and antibiotic use in the prior month. Many previously proposed factors, including smoking and livestock contact, were not significantly associated. Overall, we demonstrate that only a limited number of risk factors influence S. aureus colonisation

Introduction

Staphylococcus aureus is a major human pathogen estimated to cause up to one million deaths annually worldwide.[1] In multiple European countries, *S. aureus* bacteraemia rates are increasing [2-4], suggesting that conventional control measures are insufficient. Beyond its role as a pathogen, *S. aureus* colonises human skin, the upper respiratory tract, and the gastrointestinal tract; the primary site of colonisation is the anterior nares, where it resides in the upper and lower epidermis, hair follicles, and intracellularly. [5]

Longitudinal sampling has established that nasal *S. aureus* carriage can be classified as persistent (approximately 20% of the population), intermittent (approximately 30%), or absent (approximately 50%).[6,7] However, human challenge and immunological data support a simpler binary distinction: persistent carriers versus all others.[8] This is corroborated by nasal microbiome studies showing that the nasal microbiome of persistent carriers is dominated by *S. aureus*, whereas non-carriers exhibit greater diversity and minimal *S. aureus* abundance. Intermittent carriers lack a distinct microbiome profile and instead resemble either persistent carriers or non-carriers, suggesting they represent misclassified individuals within these two groups rather than a biologically distinct category.[8,9]

Nasal carriage is clinically important: carriers are at greater risk of *S. aureus* infection, frequently caused by the carried strain,[10,11] and prevention of carriage in high-risk groups is therefore a priority. In the UK, *S. aureus* screening and decolonisation is recommended prior to high-risk surgical procedures, including cardiac and orthopaedic surgery, and methicillin-resistant *S. aureus* (MRSA) screening is widely applied to emergency and planned admissions, though protocols vary between institutions.[12] Similar variability in screening policies exists internationally.[13-15] Notably, despite their elevated infection risk, persistent carriers have lower mortality from *S. aureus* bacteraemia than non-carriers.[8]

Several risk factors for *S. aureus* carriage have been identified, including male sex,[6,15-17] younger age,[6,15,18] white ethnicity,[6,15,17] larger household size,[17] and urban residence,[18] with lower carriage associated with tobacco smoking[6] and progestin-only contraceptive use.[7] Host genetics,[19] immunology,[20] and nasal microbiota[8,21] have also been implicated. However, many of these associations derive from small studies in selected populations, sometimes using a single swab to define carriage status.

Here we report the largest epidemiological analysis of persistent *S. aureus* nasal carriage in a community setting to date, characterising its prevalence across England and evaluating lifestyle, behavioural, and medical risk factors.

Methods

Study design and participants

Participants in one of three nationwide blood donor cohorts in England (INTERVAL[22,23], COMPARE[24] and STRIDES[25,26]) were invited to participate in the CARRIAGE study.[27] The study took place in three stages (**Supplementary Information 2**). Stage I was performed from September 2016 to December 2016 to determine the acceptability of taking two or three swabs over two or three weeks respectively. Stage II, from January 2017 to August 2017, was performed to ensure the laboratory could scale up to processing large volumes of samples received through the postal service. The main recruitment phase was stage III. This took place from February 2019 to December 2023, with a 12 month pause during the COVID-19 pandemic from April 2020 to March 2021. Potential participants received an information sheet and an invitation to participate via email. Consented participants were then sent an online baseline questionnaire to capture a range of health and lifestyle information. Participants who completed the baseline questionnaire were sent a study pack which included two or three (in stage I (pilot study)) or three (in stages II and III) nasal swabs (Sigma Transwab with Amies transport media (Medical Wire, UK)), an instruction sheet and pre-paid envelopes for return of each swab to the processing laboratory. Participants were asked to swab once a week for two or three weeks, taking the swabs first thing in the morning before showering or bathing and posting on the same day. Participants were reminded to take their swabs by text message or emails timed based on the receipt of their swabs. After their final swabs were received by the laboratory, participants were sent a feedback questionnaire to capture further data around their sampling period, experience of taking part and willingness to take part in future studies.[27]

Sample Processing

On arrival at the laboratory, swabs were removed from their transport envelopes, the sample barcode scanned into the study database and vortexed for 30 seconds. The swab was then used to inoculate Tryptic Soy Broth (TSB) with 6.5% salt (Oxoid, UK). The broths were incubated statically overnight at 37°C. The remaining transport media in the nasal swab tube (~1ml) was mixed with 500µl of glycerol and stored at -80°C for future work. After overnight incubation, 100µl of the nutrient broth was streaked to purity on Brilliance Staph 24 plates (Oxoid, UK) and incubated for up to 48 hours. Putative blue colonies of *S. aureus* were streaked to purity on Columbia blood agar plates (Oxoid, UK) and incubated overnight at 37°C. An agglutination test (Prolex™ - Blue Staph Latex

Kit (Pro-Lab Diagnostics, UK)) was used to confirm the colony was *S. aureus*. Any isolates with ambiguous agglutination results and/or phenotype were further tested using matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF). All *S. aureus* isolates were stored in Pro-lab cryovials at -80°C.

Scoping literature review and data processing

We conducted a scoping literature review of potential risk factors for *S. aureus* carriage (**see Supplementary Information 1**) and prioritised 27 characteristics with data available from the CARRIAGE study questionnaires or previously obtained in the source blood donation studies for primary evaluation (priority 1). A further 39 characteristics mainly comprising specific variables grouped in priority 1 (e.g. chronic skin conditions) were used for secondary evaluation (priority 2). Data were collected via the baseline questionnaire or at enrolment during the previous studies of blood donation. A full description of the variables is given in **Supplementary Information 3**. Participant age was the age at time of sampling in the CARRIAGE study. For descriptive analyses, age was categorised into 10-year age groups and body mass index (BMI) calculated from self-reported weight and height was categorised into underweight, normal weight, overweight and obese groups (i.e. BMI <18, 18-24, 25-29 and >30kg/m^2, respectively) according to UK National Institute for Health and Care Excellence (NICE) definitions.[28]

Statistical Analysis

Risk factors for S. aureus carriage were analysed using binary logistic regression for first-swab positivity (positive/negative) and multinomial logistic regression for three-week carriage status, classified as non-carriage (zero positive swabs), persistent carriage (three positive swabs), or undetermined (one or two positive swabs); presented as odds ratios (ORs) and relative risk ratios (RRs) respectively. Analyses were initially conducted for first-swab positivity adjusted for age and sex, to allow comparison with other studies and given that first-swab positivity has been shown previously to predict persistent carriage [29]. A multivariable model was then built iteratively by adding variables in order of ascending p-value, retaining those with p<0·05 and removing any previously entered variables that no longer met this threshold, until no further eligible variables remained. Retained variables were subsequently examined for associations with three-week carriage status using multinomial logistic regression. The discriminatory value of risk factors for persistent carriage was assessed using the area under the receiver operating characteristic (ROC) curve. All analyses were performed in Stata version 14. After correction for multiple testing, associations with p<0.002 were considered statistically significant; associations with 0.002≤p<0.05 were considered suggestive.

Results

Of 144,656 individuals invited to participate between September 2016 and December 2023, 26,586 (18.4%) consented to join the CARRIAGE study and 22,506 participants (15.6%) provided at least one swab. The bulk of sampling was conducted during study phase III (February 2019 – March 2020, and April 2021 – December 2023) (see **Supplementary information 2 -** for details of study phasing). Basic demographics are summarised in **Table 1**, and full data summaries in **Supplementary Tables 1 and 2** and **Supplementary Fig. 1**. The median age of participants was 56.8 (IQR 45.5-65.1) years, 53.0% were female, and 95% were white, 3% non-white and 2% unknown ethnicity/not disclosed. Geographical distribution of participants was comparable to that of the overall population in England (**Fig. 1a** and **Supplementary Table 3**). Participants who consented but did not return any swabs were younger, had a higher BMI, more likely to smoke tobacco, and more likely to be of non-white ethnicity (all p<0.001) (**Supplementary Table 4**).

20,842 (92.6%) participants returned all three weekly nasal swabs. The point prevalence of *S. aureus* carriage using the first swab was 35.0% (95% CI 34.4-35.7%). Prevalence was 27.6% (95% CI: 27.1-28.2%) for persistent *S. aureus* carriage (defined as three positive weekly swabs), 58.9% (95% CI 58.3-59.6%) for non-carriage (three negative swabs), and 13.4% (95% CI 13.0-13.9%) for undetermined carriage (one or two swabs positive, so not classified as either non- or persistent carriers). There was no significant variation (p=0.298) in prevalence of persistent carriage through the year or across the years (**Supplementary Fig. 2**), but there were geographical variations in the prevalence of persistent carriage, with higher prevalence in Northwest England (**Fig. 1b**).

To determine the contribution of risk factors to *S. aureus* colonisation, we first investigated the associations of 27 medical, behavioural and demographic and geographic characteristics and *S. aureus* carriage as measured by first swab positivity **(Fig. 2**, and **Supplementary Table 1).** After adjusting for age and sex, we identified ten characteristics significantly associated with *S. aureus* carriage after correction for multiple testing (p<0.002) (**Fig. 2**), including higher prevalence with younger age (p<0.0001), male sex (p<0.0001), higher BMI (p<0.0001), living in Northwest England (p=0.001), more people living in the same household (p=0.001), having any allergies (p<0.0001), having asthma (p<0.0001), having diabetes (p=0.001), and having a chronic skin condition (p<0.0001). Antibiotic use was associated with a change in *S. aureus* carriage status (overall p<0.0001); reporting antibiotic use in the week or month prior to recruitment was associated with a lower carriage prevalence (p=0.002), and conversely higher carriage prevalence if antibiotic use was in the last six months (p=0.005). Higher prevalence was observed for white ethnicity (p=0.005), having a history of *S. aureus* infection (p=0.001), and pet ownership (p=0.003) but as only a suggestive association (0.002 ≤ p < 0.05).

In multivariable adjusted analysis, six characteristics remained significant (p < 0.002) independent risk factors for first swab positivity (Table 2, Fig.3), namely: age OR 0.88 per five years), sex (OR 1.51), BMI (OR 1.12 per five units), having a chronic skin condition (OR 1.30), having had antibiotics in the prior month (OR 0.78), and living in Northwest England (OR 1.53). Additionally, six characteristics had suggestive (0.002 ≤ p < 0.05) associations, namely: non-white ethnicity (OR 0.75), more people living in the same household (OR 1.17 comparing four vs two people in the household), having allergies (OR 1.10), having asthma (OR 1.17), having had a *S. aureus* infection in the last year (OR 1.33), and having diabetes (OR 1.26). Pet ownership did not show an independent association with S. aureus first swab positivity in multivariable analysis.

We then further evaluated associations with persistent carriage (three-weekly positive) status using multinomial logistic regression. The same variables for first swab positivity were found to be independently associated with persistent vs absent carriage (**Table 2, Fig. 3**), but after correction for multiple testing (p < 0.002) only age (RR 0.89 per five years), male sex (RR 1.59), BMI (RR 1.13 per five units), having chronic skin conditions (RR 1.36), and taking antibiotics in

the prior month (RR 0.73) remained significant. Notably, men had higher colonisation rates throughout life, (Supplementary Fig.6) and the highest rates of colonisation are seen in the 20-29 years age group, with more stable prevalence between the ages of 30 and 59 and then colonisation declining sequentially in the 60-69 and 70+ years age groups (Fig. 3 and Supplementary Fig.6). Further investigation into chronic skin conditions showed that this association was driven by eczema (p<0.001), with less evidence of independent association for acne (p=0.009), and no association for psoriasis (p=0.176) (**Supplementary Table 5, Supplementary Fig.3**. Living in Northwest England (RR 1.40), non-white ethnicity (RR 0.71), more people living in the household (RR 1.20 comparing four vs two people in the household) having allergies (RR 1.11), having asthma (RR 1.16), having had a prior *S. aureus* infection (RR 1.36) and having diabetes (RR 1.28) had suggestive associations ($0.002 \leq p < 0.05$).

No association was seen for the following previously reported variables: current smoking (p=0.403), contraceptive pill or implant use (p=0.339), progesterone vs combined contraception (p=0.367), being a healthcare worker (p=0.286), having patient contact (p=0.788), having regular livestock contact (p=0.103), having had a hospital admission in the prior year (p=0.696), ABO blood group (p=0.877), Index of Multiple Deprivation score (p=0.838), urban/rural area classification (p=0.091) or census-related classification of living area (p=0.352) (**Fig. 2a** and **2b** and **Supplementary Table 2**). The key findings for this study are summarised in **Supplementary Fig. 4.**

Finally, we evaluated the contribution of risk factors to predict persistent carriage in comparison to a single swab. A multivariable risk factor model had an area under ROC curve of 0.597 (95% CI 0.587-0.607) for persistent carriage when using risk factors alone, compared to 0.952 (95% CI 0.949-0.954) when using first swab positivity alone, and 0.963 (95% CI 0.960-0.965) when using first swab positivity combined with risk factors (**Supplementary Fig. 5**).

Discussion

In this study, the largest investigation of *S. aureus* nasal colonisation to date, we examined associations between 27 demographic, behavioural, and medical characteristics and *S. aureus* carriage status in 22,506 community-based adults. Using a discovery approach based on first-swab positivity, followed by multinomial logistic regression for persistent carriage, we identified a relatively small number of factors independently associated with colonisation. Younger age, male sex, higher BMI, chronic skin conditions, and recent antibiotic use were significantly associated with persistent carriage, while residence in the Northwest of England, non-white ethnicity, larger household size, allergies, asthma, prior *S. aureus* infection, and diabetes showed suggestive associations. Notably, the risk factors associated with first-swab positivity and persistent carriage were broadly concordant.

We found that persistent colonisation rates are highest between the ages of 20-29 and then remain stable for ~30 years between the ages of 30 to 59, then declining during the two decades after 60 (Fig. 3, Supplementary Fig. 6). This decrease with age has been reported in smaller studies using a single swab,[30,31] this is the first study to specifically demonstrate persistent colonisation rates decrease with aging. The association with age is of potential of importance, as *S. aureus* bacteraemia rates increase with age;[32] for example, in England in 2024/25, *S. aureus* bacteraemia rates in persons aged >65-74 were double that for people aged 45-64.[2] Although multiple risk factors for *S. aureus* bacteraemia increase with age including increasing comorbidities, immunosenescence and hospitalisation.[32] As persistent carriers have lower mortality from *S. aureus* bacteraemia than non-carriers,[8] this suggests colonisation induces some form of protective immunity. Further studies are required to determine if the age-associated fall in persistent carriage is associated with a reduction or shift in immunity that increases susceptibly to *S. aureus* infections and bacteraemia.

Recent antibiotic use was associated with lower *S. aureus* carriage, with a greater effect size for use in the prior week than the prior month, suggesting the effect is most pronounced in the short term. Conversely, antibiotic use between one and six months prior to sampling was associated with higher carriage risk relative to use more than one year ago. This pattern likely reflects antibiotic-induced perturbation of the nasal microbiome; consistent with this, recent studies have shown that even a single course of antibiotics can have prolonged effects on the gut microbiome.[33] These findings raise the possibility of a window of elevated colonisation, and potentially infection, risk following antibiotic exposure, with implications for clinical management.

Numerous previously reported risk factors were not replicated in our study, including smoking, livestock contact, progestin-only contraceptive use, ABO blood group, deprivation, urban residence, prior hospital admission, healthcare worker status, patient contact, and seasonality. This suggests that many associations reported in earlier studies may reflect confounding, insufficient power, or risk factors that vary across time, populations, or geographic settings. Investigation of the latter two obviously warrant further large-scale studies in different geographical locations.

Smoking illustrates this point. The NHANES study (USA, 2001–2004; n=18,607) reported 27% lower odds of *S. aureus* carriage among current smokers (OR 0.73).[6] We found no such association (age- and sex-adjusted OR 0.94, p=0.403; multivariable OR 1.02, p=0.825), despite greater than 97% power to detect an effect of that magnitude. Smoking prevalence in our cohort was lower than in the UK general population (3% versus 11%)[34] and substantially lower than in the NHANES cohort (18%).[6] It is possible that the association with smoking is confined to heavy smokers, whose prevalence has declined markedly (from 20% of the UK population in 2011 to 11% in 2024)[35] alongside reductions in cigarettes smoked per day.[36] Importantly, given recent shifts in tobacco usage, we also found no association with electronic cigarette use (**Supplementary Table 2**).

Similarly, Wardyn and colleagues reported an association between swine contact and *S. aureus* colonisation in the USA (n=1,342),[37] but no effect was observed here, though small numbers of livestock-exposed participants (n=913, 4.1%) precluded species-level analysis. Nguyen and colleagues found urban residence associated with higher carriage in Vietnam (n=1,016),[18] an association not replicated here, likely reflecting population and environmental differences. Stensen and colleagues reported lower carriage with progestin-only contraceptive use (n=439),[7] which was not confirmed in our study, though we note the small sample size of this original study.

ROC analysis demonstrated that risk factors alone predicted persistent carriage poorly (AUC 0.597), whereas first-swab positivity alone performed substantially better (AUC 0.952), with marginal further improvement when risk factors were added (AUC 0.963). This underscores that while the identified

risk factors contribute to colonisation risk, other (still uncharacterised) determinants are the principal drivers of persistent *S. aureus* carriage. From a clinical standpoint, these findings reinforce that nasal swabbing and culture remain indispensable for identifying carriers in infection control contexts.

This study has notable strengths. Recruitment was independent of prior *S. aureus* infection or healthcare contact. Questionnaire design was informed by the existing literature on both carriage and infection risk factors. Completion rates were high: 91% of consenting participants completed the baseline questionnaire, 85% returned at least one swab, and 78% returned all three.[27] Sampling was conducted year-round across multiple years, spanning the COVID-19 pandemic, enabling assessment of seasonality — which had no effect on carriage rates (**Supplementary Fig. 2**). Weekly swabbing over three weeks enabled classification of participants as persistent or non-carriers, facilitating analyses not possible in studies relying on a single swab. Culture methodology incorporated broth enrichment to improve sensitivity for *S. aureus* detection.[38] Participant demographics were broadly representative of the adult English population in terms of age, sex, and geographical distribution (**Supplementary Table 3**).

Our study also had potential limitations. The cohort was drawn from blood donor populations, which could introduce selection biases: lower rates of obesity (19% versus 29% in the general English population),[39] lower smoking prevalence (3% versus 11%),[34] and fewer individuals with diabetes, since blood donation in England is restricted for those with insulin-treated or type 1 diabetes.[40] Weight eligibility criteria for donation may further explain the lower obesity prevalence. Only approximately 5% of blood donors in England are from Black, Asian, and Middle Eastern backgrounds, compared with 14% of the general population[41], though our findings on ethnicity are consistent with previous studies.[6,15,17] All lifestyle and medical data were self-reported, introducing potential recall and social desirability bias, though use of an anonymous online questionnaire should have mitigated the latter.

In conclusion, this large and systematic cohort study robustly identifies that only a relatively small number of risk factors are independently associated with persistent *S. aureus* nasal carriage, while excluding the material influence of many previously proposed factors. Our findings highlight that the principal determinants of colonisation by this important pathogen remain to be elucidated, and that nasal swab culture remains essential for carrier identification in clinical and infection control practice.

Declarations

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Ethics

The CARRIAGE study received ethics committee approval from the National Research Ethics Service Committee Northwest - Lancaster Research Ethics Committee, 27/06/2016, REC reference: 16/NW/0507, IRAS project ID: 202688. All participants provided informed consent. The study is registered at ISRCTN: ISRCTN10474633. The REC references for the three contributing blood donor cohorts are 11/EE/0538 (INTERVAL), 15/EE/0335 (COMPARE) and 18/EE/0284 (STRIDES).

Contributors

BB, MW, SK, CP, KLB, PPN, STG, JB, CS, AA, LS, KR, RMB, MM, DN, SB, EJ, SD, MJ, AF, EF, JG, BH, NL, BM, NT and EMH contributed to data collection and/or laboratory investigation. BB, SK, KLB, DA, and EMH performed the formal analysis. BB, CM, AM, KLB, SB, EJ, SD, MJ, RH, CC, EB, SS, JM, AO, HD and EMH contributed to project administration and/or resources. CM, AM, CC, ASB, JAG, CAA, JP, JD, SJP and EMH supervised the study. JAG, CAA, JP, JD, SJP and EMH were involved in funding acquisition. BB, SK, DA and EMH completed the original draft and visualisation. All authors reviewed and approved the manuscript.

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Conflicts of interest

CAA has received consultancy and/or speaker fees from Genomics plc, BridgeBio and GSK. JD serves on scientific advisory boards for AstraZeneca, Novartis, and UK Biobank, and has received multiple grants from academic, charitable and industry sources outside of the submitted work. ASB has received grants from AstraZeneca, Bayer, Biogen, Merck, Novartis and Sanofi outside of the submitted work.

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Tables

Table 1. Study demographics

Characteristic	N	Median (IQR) or n (%)
Sex	22506	
Male	22506	10570 (47%)
Female	22506	11936 (53%)
Age (years)	22506	56.8 (45.5, 65.1)
Age group (years)	22506	
<20	22506	8 (0.0%)
20	22506	1139 (5%)
30	22506	2665 (12%)
40	22506	3625 (16%)
50	22506	5867 (26%)
60	22506	6750 (30%)
70+	22506	2452 (11%)
Body mass index (kg/m^2)	21343	25.6 (23.3, 28.8)
Current tobacco smoking	22433	
Yes	22433	752 (3%)
No	22433	21631 (96%)
Don’t know / prefer not to answer	22433	50 (0.2%)
Ethnic group	22503	
White	22503	21466 (95%)
Non-white	22503	682 (3%)
Unknown/ND	22503	355 (2%)
Region	22231	
Northeast	22231	855 (4%)
Northwest	22231	2799 (13%)
Yorkshire and The Humber	22231	2473 (11%)
East Midlands	22231	2272 (10%)
West Midlands	22231	1955 (9%)
East of England	22231	3404 (15%)
London	22231	2515 (11%)
Southeast	22231	3365 (15%)
Southwest	22231	2593 (12%)
ABO blood group	22498	
A	22498	8494 (38%)
B	22498	2275 (10%)
O	22498	11121 (49%)
AB	22498	608 (3%)
Have any allergies	22349	
Yes	22349	7488 (34%)
No	22349	14570 (65%)
Don’t know/prefer not to answer	22349	291 (1%)
Had previous *S. aureus* infection	19926	
Yes - only once	19926	600 (3%)
Yes - recurrent infection	19926	8 (0.0%)

No	19926	18437 (93%)
Don't know/prefer not to answer	19926	881 (4%)
S. aureus carriage status	22506	
First swab positive	22506	7884 (35%)
Persistent carriage	22506	6222 (28%)
Undetermined carriage	22506	3025 (13%)

Table 2. Multivariable analysis of risk factors associated with *S. aureus* carriage.

	First swab positivity		Three-week carriage				
	Positive vs Negative		Undetermined vs Absent		Persistent vs Absent		Overall*
Characteristic	OR (95% CI)	p	RR (95% CI)	p	RR (95% CI)	p	p
Age (per 5 years)	0.88 (0.85, 0.90)	**<0.0001**	0.82 (0.78, 0.85)	**<0.0001**	0.89 (0.87, 0.92)	**<0.0001**	**<0.0001**
Male sex	1.51 (1.42, 1.62)	**<0.0001**	1.06 (0.96, 1.17)	0.270	1.59 (1.48, 1.71)	**<0.0001**	**<0.0001**
BMI (per 5 Kg/m^2)	1.12 (1.09, 1.16)	**<0.0001**	1.08 (1.03, 1.14)	**0.003**	1.13 (1.09, 1.17)	**<0.0001**	**<0.0001**
Chronic skin conditions	1.30 (1.18, 1.43)	**<0.0001**	1.18 (1.02, 1.36)	**0.029**	1.36 (1.22, 1.50)	**<0.0001**	**<0.0001**
Antibiotic usage		**<0.001**		0.144		**<0.0001**	**<0.0001**
In the last week	0.64 (0.48, 0.84)	0.002	0.82 (0.55, 1.23)	0.346	0.62 (0.45, 0.84)	0.002	
In the last month	0.78 (0.61, 0.98)	0.036	1.23 (0.90, 1.68)	0.193	0.73 (0.56, 0.95)	0.019	
In the last three months	0.91 (0.77, 1.07)	0.271	1.11 (0.87, 1.41)	0.402	0.98 (0.82, 1.17)	0.847	
In the last six months	1.18 (1.02, 1.37)	0.027	1.14 (0.91, 1.42)	0.259	1.22 (1.04, 1.43)	0.017	
In the last year	1.12 (0.99, 1.27)	0.071	1.04 (0.86, 1.25)	0.700	1.15 (1.01, 1.31)	0.038	
More than a year ago	1 (Reference)		1 (Reference)		1 (Reference)		
Never	1.14 (0.93, 1.39)	0.194	1.41 (1.06, 1.87)	0.018	1.19 (0.95, 1.48)	0.126	
Region of England		**0.001**		0.224		**0.008**	**0.040**
Northeast	1 (Reference)		1 (Reference)		1 (Reference)		
Northwest	1.53 (1.26, 1.86)	<0.0001	1.45 (1.08, 1.95)	0.014	1.40 (1.14, 1.72)	0.001	
Yorkshire and The Humber	1.32 (1.08, 1.60)	0.006	1.34 (0.99, 1.81)	0.059	1.25 (1.02, 1.55)	0.035	
East Midlands	1.26 (1.03, 1.53)	0.024	1.19 (0.87, 1.61)	0.276	1.13 (0.91, 1.39)	0.275	
West Midlands	1.22 (0.99, 1.49)	0.058	1.23 (0.90, 1.67)	0.196	1.20 (0.97, 1.49)	0.099	
East of England	1.22 (1.01, 1.47)	0.044	1.18 (0.88, 1.58)	0.269	1.10 (0.89, 1.34)	0.376	
London	1.34 (1.10, 1.63)	0.004	1.22 (0.90, 1.66)	0.201	1.23 (0.99, 1.52)	0.057	
Southeast	1.29 (1.07, 1.56)	0.007	1.30 (0.98, 1.75)	0.073	1.19 (0.97, 1.46)	0.088	
Southwest	1.24 (1.02, 1.50)	0.034	1.35 (1.00, 1.82)	0.050	1.13 (0.92, 1.40)	0.244	
Number in household		**0.010**		**<0.0001**		**0.003**	**<0.0001**
1	0.98 (0.89, 1.08)	0.675	0.84 (0.72, 0.98)	0.029	1.01 (0.91, 1.12)	0.845	
2	1 (Reference)		1 (Reference)		1 (Reference)		
3	1.10 (1.00, 1.20)	0.057	1.13 (0.98, 1.30)	0.083	1.15 (1.04, 1.27)	0.008	
4	1.17 (1.06, 1.29)	0.002	1.39 (1.20, 1.60)	<0.0001	1.20 (1.08, 1.34)	0.001	
5+	1.09 (0.93, 1.27)	0.303	1.47 (1.18, 1.83)	0.001	1.16 (0.98, 1.39)	0.092	
Have any allergies	1.10 (1.03, 1.18)	**0.008**	0.89 (0.80, 0.99)	**0.030**	1.11 (1.03, 1.20)	**0.009**	**0.001**
Have asthma	1.17 (1.04, 1.32)	**0.009**	1.11 (0.92, 1.33)	0.269	1.16 (1.02, 1.32)	**0.024**	0.068
Ever had *S. aureus* diagnosed		**0.009**		0.465		**0.009**	**0.042**
Yes – only once	1.33 (1.11, 1.60)	0.002	1.16 (0.87, 1.53)	0.308	1.36 (1.12, 1.65)	0.002	
Yes – recurrent infection	1.12 (0.24, 5.18)	0.889	2.10 (0.27, 16.40)	0.480	1.14 (0.19, 6.91)	0.888	
No	1 (Reference)		1 (Reference)		1 (Reference)		
Non-white ethnic group	0.75 (0.62, 0.91)	**0.004**	0.98 (0.75, 1.28)	0.876	0.71 (0.57, 0.89)	**0.003**	**0.009**
Have diabetes	1.26 (1.01, 1.58)	**0.040**	0.98 (0.67, 1.43)	0.900	1.28 (1.01, 1.62)	**0.040**	0.096

* Overall p value jointly testing whether there is an association with either persistent or undetermined *S. aureus* carriage for each variable.

Figures

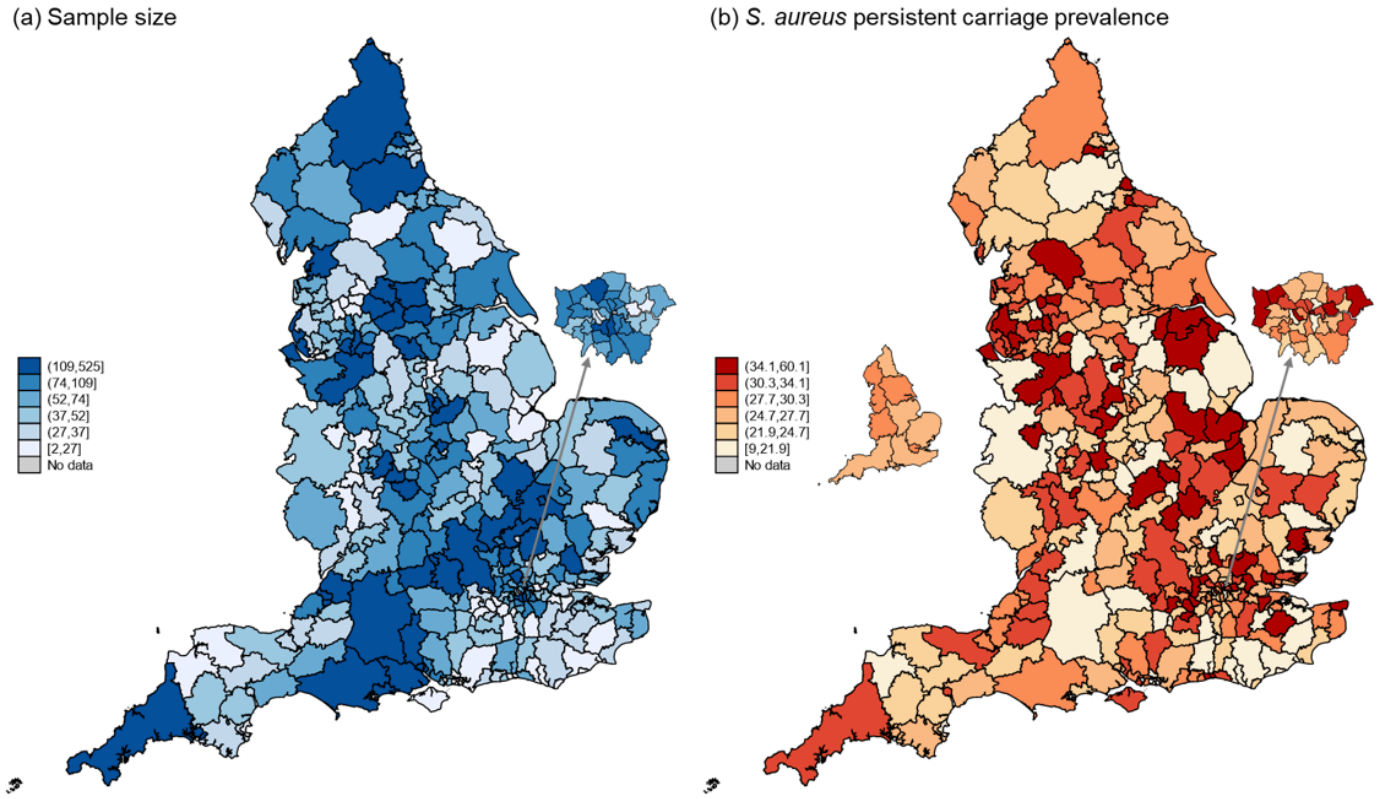


Figure 1

Distribution of CARRIAGE study participants (panel a) and estimated prevalence of persistent *S. aureus* carriage (panel b) by England regions and local authority regions.

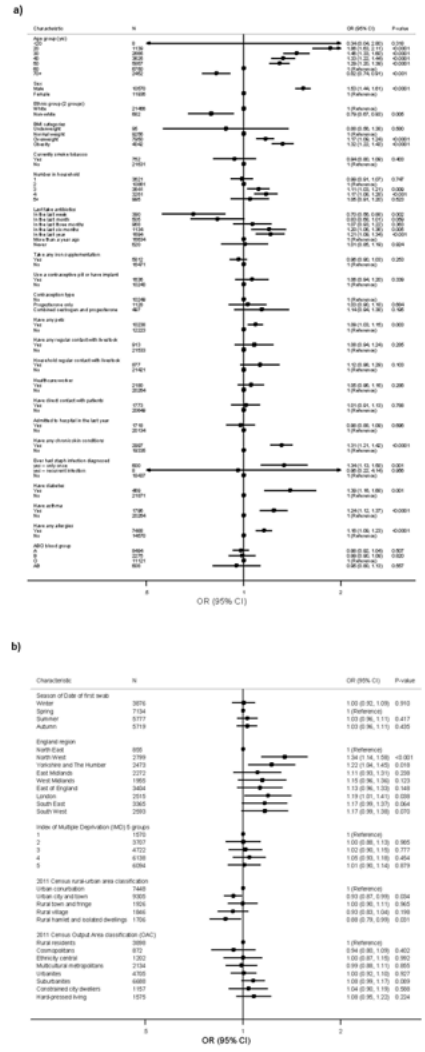


Figure 2

Associations between risk factors and first swab positivity, adjusted for age and sex

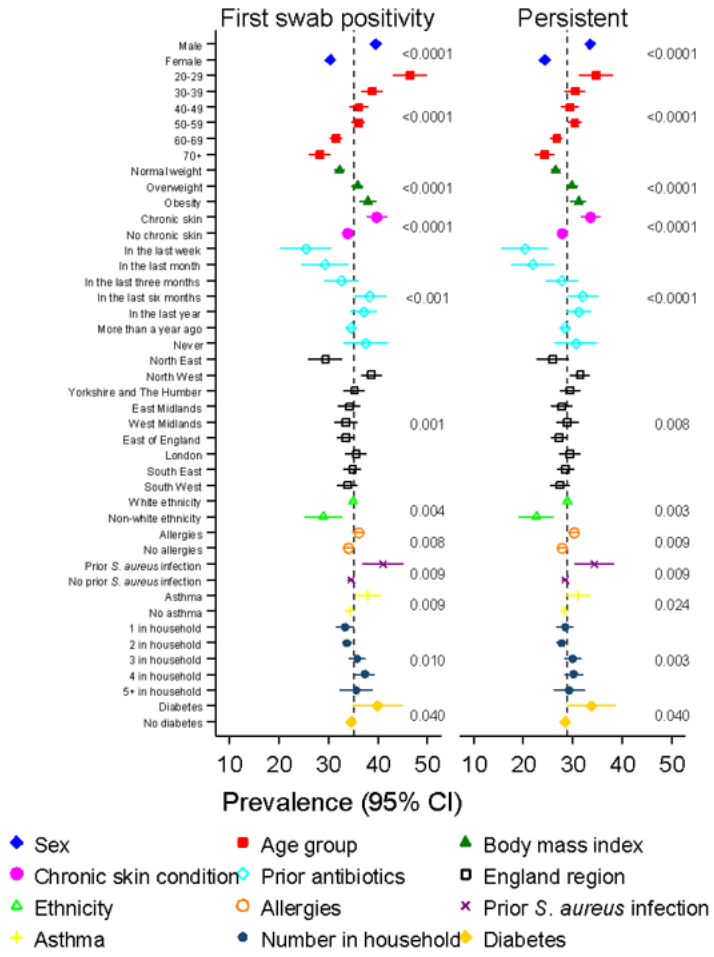


Figure 3

Multivariable analysis of risk factors for *S. aureus* carriage.

Adjusted for age, sex, BMI, ethnicity, chronic skin, antibiotics, region, household number, allergies, asthma, previous staph infection, diabetes

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