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Nasopharyngeal Carriage of *Neisseria meningitidis* in 181 Hajj and Umrah Pilgrims in Türkiye: Pre- and Post-Travel Prevalence and Serogroup Distribution

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Background: Meningococcal carriage and serogroup distribution are closely linked to the epidemiology of invasive meningococcal disease. Mass gatherings such as Hajj and Umrah may alter carriage dynamics. Monitoring carriage before and after travel can inform vaccination strategies. This prospective observational study aimed to evaluate nasopharyngeal carriage of *Neisseria meningitidis* in 181 Hajj and Umrah pilgrims in Turkey.

Material/Methods: A total of 247 participants were enrolled before travel, and 181 participants provided paired pre- and post-travel samples. Paired nasopharyngeal samples were collected before departure and after return. Carriage and serogroups were identified by single-tube multiplex real-time polymerase chain reaction assay. Changes in carriage status were analyzed with McNemar's test.

Results: Among 181 participants with paired samples, meningococcal carriage increased significantly after travel (8.2% vs 14.4%; McNemar χ^2=9.76; *P*=0.002), with acquisition more frequent than loss (28 vs 9 cases; odds ratio, 3.11; 95% CI, 1.47-6.58). New acquisitions were predominantly due to non-vaccine serogroups, particularly serogroup B (15 cases) and serogroup X (8 cases). Among Hajj participants (n=112), carriage increased significantly (9.8% vs 18.7%; *P*=0.002), mainly driven by serogroup B, whereas no significant change was observed among Umrah participants (5.7% vs 7.2%; *P*=0.48).

Conclusions: Meningococcal carriage increased significantly after travel, particularly among Hajj pilgrims, with new acquisitions predominantly involving serogroups B and X. These findings highlight the potential role of non-vaccine serogroups in post-travel carriage and the need for continued surveillance.

Keywords: Carrier State • Nasopharynx • Serogroup • Epidemiology • *Neisseria meningitidis* • Vaccination • Polymerase Chain Reaction

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Introduction

The Hajj and Umrah pilgrimages to Saudi Arabia represent one of the largest recurrent mass gatherings worldwide, bringing together millions of individuals from diverse geographical regions and attracting more than 30 million pilgrims annually [1-3]. Dense crowds, close interpersonal contact, shared accommodation, and diverse international participation of pilgrims facilitate the rapid transmission of infectious agents, including *Neisseria meningitidis* [4,5]. The Hajj and Umrah pilgrimages have historically played an important role in the global transmission of meningococcal disease and have been associated with an increased risk of invasive meningococcal disease international outbreaks [1-9], most notably those linked to the Hajj pilgrimage, including serogroup A in 1987 and serogroup W in 2000-2001 [1]. These outbreaks led to the introduction of mandatory quadrivalent meningococcal vaccine (MenACWY) vaccination for pilgrims entering Saudi Arabia [2]. Currently, Saudi Arabia mandates quadrivalent MenACWY vaccination for all pilgrims aged 1 year and older [1]. The vaccine must be administered at least 10 days before arrival and is valid for 3 to 5 years, depending on the vaccine type [10,11]. Despite this policy, vaccination compliance remains suboptimal, particularly among Umrah pilgrims, with only 54% coverage reported as of March 2025 [12]. Recent surveillance has continued to identify travel-associated invasive meningococcal disease cases. In 2024, cases were reported among returning pilgrims in the United Kingdom, France, and the United States, with most affected individuals being unvaccinated [3,13]. In early 2025, Saudi Arabia reported 11 confirmed invasive meningococcal disease cases among Umrah pilgrims, all caused by serogroup W [12]. These cases were temporally associated with Umrah and Ramadan travel, whereas the outbreak declined during the Hajj period when vaccination compliance was highest [3]. Many of these infections belonged to the hypervirulent MenW clonal complex 11 (cc11) Hajj-associated lineage, which has historically been associated with outbreaks [2,3]. Importantly, Hajj and Umrah differ in several epidemiological aspects, including crowd density, international diversity, duration of stay, and vaccination compliance across countries, which can influence transmission dynamics [1,7].

In Turkey, meningococcal disease epidemiology is dynamic and differs from global trends [14]. Serogroup B has emerged as a predominant cause of invasive meningococcal disease, with serogroups W, A, and Y also contributing, while serogroup C remains rare in the absence of routine vaccination. Serogroup W was first identified in Turkey in 2001, and by 2012 it accounted for most meningitis cases, likely reflecting travel-related transmission associated with the Hajj and Umrah pilgrimages [14-16]. A nationwide multicenter carriage study conducted in 2016 among adolescents and young adults reported an overall meningococcal carriage rate of 6.3%, with serogroup W predominance [17]. In 2018, a similar study in the same cities found a carriage rate of 7.5% among children and adolescents, with serogroup X emerging as the predominant serogroup [18]. Following the first phase of the COVID-19 pandemic in Turkey, meningococcal carriage rates among children and young adults aged 0 to 24 years increased to 8.5%, particularly among individuals aged 15 to 18 years (19.4%) and 19 to 24 years (11.2%), predominantly due to serogroup B, followed by serogroup W [19]. Quadrivalent conjugate vaccines (MenACWY) and MenB vaccines are not included in the national immunization program in Turkey and are used mainly in private practice. Routine MenACWY vaccination is primarily administered to Hajj and Umrah pilgrims and military personnel [19].

Continuous surveillance of meningococcal carriage among pilgrims remains an important component of global public health preparedness, as the epidemiology is heterogeneous and not fully understood [2]. A systematic review and meta-analysis by Samannodi et al [5] reported a pooled prevalence of meningococcal disease or carriage of 15.9% (95% CI, 4.45-27.4) during mass gatherings or travel events, including the Hajj pilgrimage [5]. Another systematic review, including 21 studies and 23 552 participants, demonstrated that meningococcal carriage increases during Hajj, with overall carriage increasing from 1.6% before Hajj to 3.4% after [8]. Carriage studies show that the most clinically important serogroups are A, B, C, W, X, and Y, although their distribution varies across settings and time periods [2]. Despite vaccination policies, meningococcal carriage can still occur among vaccinated individuals, allowing ongoing transmission during and after pilgrimage travel [2]. In the era of widespread MenACWY vaccination, the epidemiology of meningococcal carriage may be shifting toward non-MenACWY vaccine serogroups, such as B and X [1,2,5].

To the best of our knowledge, limited paired pre- and post-travel sampling data are available on meningococcal carriage dynamics among MenACWY-vaccinated Hajj and Umrah pilgrims, particularly from countries such as Turkey, which send large numbers of pilgrims annually and have a distinct meningococcal epidemiological profile. Furthermore, differences between Hajj and Umrah travel—including crowd density and duration of stay—may influence transmission patterns but remain insufficiently explored. Therefore, this study aimed to evaluate nasopharyngeal carriage of *N. meningitidis* in 181 Hajj and Umrah pilgrims in Turkey.

Material and Methods

Ethics Approval

The study was approved by the Clinical Research Ethics Committee at Eskisehir Osmangazi University (November 27,

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2018; decision number 5). All procedures followed the ethical standards of the institutional and national research committees, in accordance with the Declaration of Helsinki and its later amendments. All participants were informed about the study objectives and procedures, and written informed consent was obtained from all participants prior to enrollment and sample collection.

Study Design and Setting

This prospective observational study evaluated nasopharyngeal carriage of *N. meningitidis* among Hajj and Umrah pilgrims in Turkey using paired pre- and post-travel sampling from the same participants. Participant recruitment and sample collection were conducted during the 2019 Hajj and Umrah pilgrimage period.

Study Population and Data Collection

Eligible participants were individuals planning to travel to Saudi Arabia for Hajj or Umrah who attended the pre-travel health assessment and agreed to participate in the study. Individuals who had received systemic antibiotics within the previous 4 weeks or who declined participation were excluded. A structured questionnaire was used to collect demographic and clinical variables previously identified in the literature as potential risk factors for meningococcal carriage, including age, sex, smoking status, household size, chronic disease history, medication use, and travel duration. To reduce the potential impact of antimicrobial exposure on carriage detection, participants who reported receiving antibiotic therapy during travel for any reason were excluded from the paired post-travel analysis.

Bacterial Identification

Nasopharyngeal swab specimens were collected from participants at 2 time points: prior to departure and shortly after return from Saudi Arabia, typically within 1 to 5 days following arrival in Turkey, during routine post-travel health assessments. Nasopharyngeal samples were obtained by trained study personnel using sterile swabs (Copan Diagnostics, Carlsbad, CA, USA), transported in Amies medium with activated charcoal (DeltaLab, Barcelona, Spain), and stored at -80°C until analysis.

Phosphate buffered saline solution (1000 µL) was added to the microtube and mixed with the swab for approximately 1 to 2 minutes. DNA extraction was performed using the QuickGene DNA whole blood kit (DB-S, Osaka, Japan) with the QuickGene-Mini80 semi-automatic device, according to the manufacturer's instructions. Briefly, 200 µL of the sample was treated with lysis buffer and Proteinase K, incubated at 56 °C for 5 minutes, and processed through binding, washing, and elution steps. DNA was stored at -80°C until analysis.

The presence of *N. meningitidis* was determined by single-tube multiplex real-time polymerase chain reaction (PCR) assay targeting the sodC, ctrA, and porA genes, as previously described [19]. Additional targets, including tauE and metA, were used to improve detection sensitivity. Samples with a cycle threshold value of 35 or lower were considered positive. PCR-positive samples were subsequently analyzed for serogroup determination using capsular gene targets specific for serogroups A (orf-2), B, C, W, Y (siaD), and X (ctrA). Additional serogroups E, Z, and H were evaluated using conventional PCR followed by electrophoresis on a 2% agarose gel. Samples positive for *N. meningitidis* but negative for all serogroup-specific assays were classified as non-groupable strains [19].

Study Endpoints

The primary outcome of the study was the presence of nasopharyngeal *N. meningitidis* carriage before and after travel. Secondary outcomes included serogroup distribution and demographic or clinical factors potentially associated with carriage.

Sample Size Calculation

Based on prior carriage rates and a target power of 90% with a significance level of 5% (α=0.05), the minimum required sample size was calculated as 200 participants. To compensate for potential losses and unusable samples, the sample size was increased by 20%, yielding a final target of 240 individuals.

Statistical Analysis

Statistical analyses were performed using JASP statistical software (JASP Team, 2025, Version 0.95.3; University of Amsterdam, Netherlands). Normality of distribution was assessed using the Shapiro-Wilk test. Continuous variables are expressed as mean±standard deviation. Categorical variables are expressed as counts and percentage, n (%). Differences between independent categorical variables were assessed using the chi-square test, while continuous variables were compared using independent samples *t* tests where appropriate. Participants with incomplete paired samples were excluded from paired analyses (complete-case analysis).

For participants with paired pre- and post-travel samples, changes in carriage status were evaluated using McNemar's test for paired binary data. McNemar's test is a non-parametric statistical test applied to paired nominal data to assess whether there is a statistically significant difference in the proportions of discordant pairs—specifically, participants who shifted from carriage-negative to carriage-positive (acquisition) or from carriage-positive to carriage-negative (clearance) between the 2 time points. The test statistic is calculated based solely on the discordant pairs, making it appropriate for within-subject,

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before-and-after comparisons of binary outcomes. Where cell counts were small, McNemar's exact test was applied. The matched odds ratio (OR) with 95% CI was calculated to quantify the relative likelihood of carriage acquisition vs clearance following travel. Subgroup analyses were performed separately for Hajj and Umrah participants to evaluate differences in carriage dynamics between the 2 pilgrimage types. Serogroup-specific changes in carriage were also analyzed using McNemar's exact test where applicable. The association between post-travel carriage status and potential risk factors, including sex, chronic disease, medication use, smoking history, and duration of stay, was assessed using the chi-square test for categorical variables and independent samples *t* test for continuous variables. Missing data were handled using complete-case analysis. Because the analyses were primarily exploratory and limited in number, no formal adjustment for multiple comparisons was applied. A *P* value <0.05 was considered statistically significant.

Results

Study Cohort and Pre-Travel Findings

In 2019, a total of 247 individuals preparing to travel to Saudi Arabia for Hajj or Umrah were enrolled during their pre-travel assessments. All participants had received the quadrivalent conjugate meningococcal vaccine (MenACYW-TT, Nimenrix, Pfizer, USA). Pre-travel nasopharyngeal swab samples were collected and analyzed for *N. meningitidis* carriage. Among all 247 participants enrolled before travel, 34 (13.7%) were positive for *N. meningitidis*. Twenty-six samples were non-groupable. Serogroup B was identified in 4 individuals (1.6%), serogroup X in 3 (1.2%), and serogroup W in 1 individual (0.4%). Among the 181 participants with paired pre- and post-travel samples, the pre-travel carriage rate was 8.2%.

Post-Travel Carriage and Participant Characteristics

A total of 181 (108 women and 73 men) participants met the inclusion criteria at follow-up and provided post-travel swab samples. Chronic medical conditions were reported by 103 participants (56.9%), and 99 (54.6%) individuals were on regular medications due to chronic conditions. Forty-nine participants (27.1%) had previously traveled to Saudi Arabia for Hajj or Umrah, and 41 individuals (22.7%) were current smokers. In the entire cohort with paired samples (n=181), meningococcal carriage increased significantly after travel (8.2% vs 14.4%). McNemar's test demonstrated a significant increase in carriage following travel (χ^2=9.76; *P*=0.002). Acquisition of carriage was more frequent than loss (28 vs 9 cases), corresponding to a matched odds ratio of 3.11 (95% CI, 1.47-6.58) (**Figure 1**). Among the 181 participants, 28 acquisitions of meningococcal carriage occurred, most commonly involving

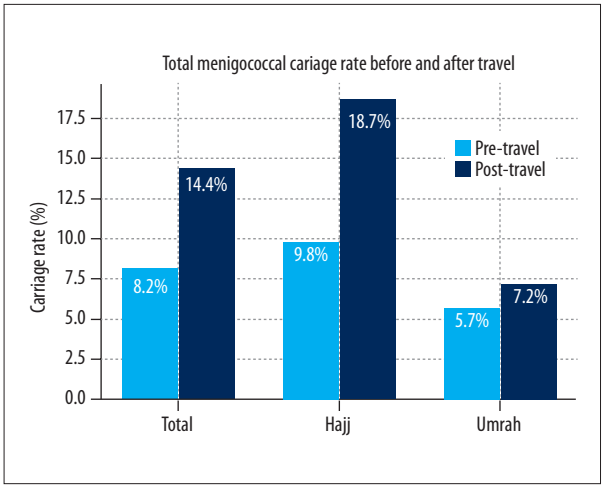

Figure 1. Comparison of meningococcal nasopharyngeal carriage rates before and after travel to Saudi Arabia among Hajj and Umrah participants. Blue bars represent pre-travel carriage rates and dark blue bars represent post-travel carriage rates for the total group (N=181), Hajj participants (n=112), and Umrah participants (n=69). Carriage rates increased significantly in the overall cohort (8.2% vs 14.4%; McNemar χ^2=9.76; *P*=0.002) and among Hajj participants (9.8% vs 18.7%; McNemar χ^2=9.97; *P*=0.002), whereas no statistically significant change was observed among Umrah participants (5.7% vs 7.2%; *P*=0.48). *P* values were calculated using the McNemar test for paired proportions.

serogroup B (15 cases) and serogroup X (8 cases), while 9 participants lost carriage. Two participants demonstrated serogroup replacement, changing from X to B and from non-groupable to X. Overall, more than half of new acquisitions involved serogroup B, highlighting the predominance of non-vaccine serogroups among newly acquired carriage. During the post-travel period, serogroup B was identified in 15 individuals (8.3%), serogroup X in 7 (3.9%), and serogroup W in 1 (0.6%). Four cases (2.2%) were non-groupable. No statistically significant association was observed between carrier status and sex, chronic disease, medication use, or smoking history.

Hajj Participants: Pre- and Post-Travel Carriage

In the Hajj participant group (n=112), the before-travel meningococcal carriage rate was 9.8% (n=11) and the after-travel rate was 18.7% (n=21). Among Hajj participants with paired samples, meningococcal carriage increased significantly after travel (McNemar χ^2=9.97; *P*=0.002). The matched odds ratio indicated that acquisition of carriage after travel was more frequent than loss of carriage (OR, 3.83; 95%, CI 1.56-9.39). Serogroup B carriage was not detected before travel but was identified in 11.6% of participants after travel. All serogroup B detections represented new acquisitions (13 cases), with no losses observed. McNemar's exact test confirmed a significant increase

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in serogroup B carriage after travel (P<0.001). Serogroup X rose from 1.8% (n=2) to 4.5% (n=5). Non-groupable strains decreased from 6.3% (n=7) before travel to 3.6% (n=4) after travel. No serogroups A, C, or Y were detected. Two participants were positive at both time points but showed serogroup replacement: one changed from serogroup X to B, and the other from non-groupable to serogroup X.

Umrah Participants: Pre- and Post-Travel Carriage

Among Umrah participants with paired samples (n=69), meningococcal carriage did not change significantly after travel (5.7% vs 7.2%; McNemar χ^2=0.50; P=0.48). The matched odds ratio suggested no significant difference between acquisition and loss of carriage (OR, 1.67; 95% CI, 0.39-7.03). At baseline (before travel), 4 individuals (5.7%) were carriers: 3 with serogroup B (4.4%) and 1 with serogroup X (1.4%). After travel, 5 individuals (7.2%) were carriers: 3 with serogroup B (4.4%) and 2 with serogroup X (2.8%). Changes in carriage status included 5 new acquisitions and 3 losses. No serogroup W or non-groupable strains were detected among Umrah participants.

Age, Length of Stay, and Risk Factors

The mean age of Hajj participants (62.6±8.2 years) was significantly older than that of Umrah participants (56.2±14.9 years; P<0.001). Likewise, the duration of stay was significantly longer among Hajj participants (37.4±14.7 days) compared with Umrah participants (19.9±4.6 days; P<0.001). The average duration of stay was significantly greater among carriers (35.3±6.3 days) than non-carriers (30.2±9.4 days; P<0.001), suggesting an association between longer duration of stay and carriage.

Discussion

This study assessed nasopharyngeal *N. meningitidis* carriage and serogroup distribution among Turkish Hajj and Umrah participants using paired pre- and post-travel sampling. Among the 181 participants with paired samples, meningococcal carriage increased significantly after travel (8.2% vs 14.4%; McNemar χ^2=9.76; P=0.002), with acquisition more frequent than loss (28 vs 9 cases; matched OR, 3.11; 95% CI, 1.47-6.58). The majority of newly acquired isolates belonged to serogroup B (15 cases) and serogroup X (8 cases). Notably, no carriage of MenACWY vaccine-covered serogroups was detected at follow-up, a finding that may suggest reduced carriage of these strains in a fully vaccinated cohort. Carriage increased significantly among Hajj participants (9.8% vs 18.7%; P=0.002) but not among Umrah participants (5.7% vs 7.2%; P=0.48). Longer duration of stay was significantly associated with carriage acquisition, while no significant associations were observed with sex, chronic disease, medication use, or smoking history.

Previous studies have consistently demonstrated that mass gatherings such as the Hajj and Umrah pilgrimages provide conditions that facilitate meningococcal transmission through intense crowding, shared accommodation, and international population mixing [2,5]. Earlier investigations among pilgrims reported relatively low but measurable carriage prevalence, with serogroup distribution varying across time periods and study populations [1,2,5,7]. Ceyhan et al [20] reported that carriage among Turkish pilgrims increased from 13% before Hajj to 27% after Hajj, with 91% of isolates belonging to serogroup W. At that time, quadrivalent polysaccharide meningococcal vaccines were used, which are known to have limited effect on nasopharyngeal carriage. These findings contributed to the subsequent adoption of conjugate vaccines, which are capable of reducing both disease and carriage [20]. In a later study, Tezer et al [21] demonstrated a significant reduction in carriage of MenACWY-covered serogroups following vaccination with quadrivalent conjugate vaccines (3.9% vs 0.4%), highlighting the effectiveness of conjugate vaccination in interrupting transmission of serogroups A, C, W, and Y. In our study, the absence of carriage of these vaccine-covered serogroups at follow-up may similarly reflect the effect of widespread MenACWY vaccination among pilgrims.

Recent literature suggests that meningococcal epidemiology in mass gathering settings continues to evolve [22]. In addition, genomic surveillance studies have documented international cases of invasive meningococcal disease associated with Umrah-related travel, particularly involving hypervirulent MenW: cc11 lineages [3]. These findings demonstrate that pilgrimage-associated transmission remains a relevant global public health concern. Within this evolving epidemiological context, the present study provides updated carriage data from a vaccinated cohort and documents the presence of non-vaccine serogroups after travel.

Several systematic reviews have further illustrated the heterogeneity of meningococcal carriage associated with mass gatherings. A recent systematic review and meta-analysis by Alhajaji et al [2] specifically examined *N. meningitidis* carriage among Hajj and Umrah pilgrims and reported increased post-travel carriage rates with considerable heterogeneity in serogroup distribution across studies, findings that are consistent with our observations. Samannodi et al [5] reported a pooled prevalence of meningococcal disease or carriage of 15.9% (95% CI, 4.45-27.4) among individuals attending mass gatherings or traveling internationally. Another systematic review including 21 studies and 23 552 participants showed that carriage increased during Hajj, rising from 1.6% before travel to 3.4% after pilgrimage [8]. These analyses also demonstrated that carriage prevalence and serogroup distribution vary substantially across settings and time periods. Across studies, the most clinically relevant serogroups include A, B, C, W, X, and Y, although

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their relative frequencies differ geographically and temporally [2,5,8]. Importantly, increasing detection of serogroups B and X in recent studies suggests a shift toward non-vaccine serogroups in the era of widespread MenACWY vaccination.

Our findings are consistent with this emerging pattern. In our cohort, carriage increased significantly following travel, and most newly acquired isolates belonged to serogroups B and X. Serogroup B carriage was not detected before travel but was identified in 11.6% of participants after travel. This observation aligns with recent studies suggesting that serogroup B is becoming increasingly prominent among vaccinated populations participating in mass gatherings [5]. For example, a study conducted in Saudi Arabia reported a carriage rate of 3.4% among individuals arriving in the country after widespread vaccination, with 67% of isolates belonging to serogroup B [23]. Samannodi et al's meta-analysis [5] showed a higher prevalence of serogroup B meningococcal disease or carriage among individuals attending mass gatherings. These findings suggest that non-vaccine serogroups may become relatively more prominent in carriage patterns in settings where MenACWY vaccination is widely implemented.

Serogroup X was also detected in both the pre- and post-travel samples in our study. This observation is consistent with national surveillance data from Turkey, which have reported increasing detection of serogroup X among adolescents and young adults during recent years [18]. Although serogroup X historically accounted for a relatively small proportion of meningococcal disease globally, increasing detection in carriage and invasive disease highlights the importance of continued monitoring. Meta-analysis data from Samannodi et al [5] also identified serogroup X in mass gathering settings, although with relatively low prevalence (pooled prevalence 0.23%; 95% CI, -0.14% to 0.61%). Together, these observations emphasize that serogroup X remains an emerging strain that warrants ongoing surveillance.

Another notable finding of our study was the difference between Hajj and Umrah participants. Carriage increased significantly among Hajj participants but not among Umrah participants. This difference may be explained by several epidemiological factors. Hajj involves a substantially larger number of pilgrims from diverse countries, higher crowd density, and longer duration of stay compared with Umrah. In our cohort, Hajj participants had significantly longer travel durations, and carriage was more common among individuals who stayed longer in Saudi Arabia. These findings support the hypothesis that prolonged exposure and greater population mixing may contribute to increased transmission during Hajj. In our study, no statistically significant association was observed between carrier status and sex, chronic disease, medication use, or smoking history. A recent meta-analysis showed that age, sex, smoking, and vaccination status were not consistently associated with increased carriage risk across studies [5].

Participants in our cohort were predominantly older adults, with a mean age of 62.6 years among Hajj participants and 56.2 years among Umrah participants. More than half of participants reported chronic medical conditions and regular medication use. Recent epidemiological studies have highlighted an increasing burden of invasive meningococcal disease among older adults, particularly among individuals aged 60 years or older, who may experience higher mortality and atypical clinical presentations [24]. In Turkey, between 2022 and 2023, the percentage of meningococcal carriage was found to be 13.9% in older adults, and the most common serogroup was MenY [25]. The MenY serogroup, which is one of the most important causes of invasive meningococcal disease (especially in pneumonia cases) in people older than 65 years, was the most frequently carried serogroup in people over 65 years of age [25]. These findings highlight the importance of considering older adults as a potentially vulnerable population and reinforce the importance of vaccination strategies for pilgrims in this age group [25,26].

The overall pre-travel carriage rate in our cohort (13.7%) was slightly higher than reported in several other studies of Hajj and Umrah pilgrims, which have typically documented pre-travel carriage rates between 1% and 10% depending on geographic setting and detection methods [1,9,27]. One possible explanation is the exclusion of participants who had recently received antibiotic therapy. In real-world settings, many pilgrims may receive antibiotics for respiratory infections before or during travel [28], which may suppress nasopharyngeal colonization and lead to false-negative carriage detection. By excluding individuals with recent antibiotic exposure, our study may have reduced this potential bias and improved the accuracy of observed carriage prevalence, although this approach may also have slightly limited the generalizability of the findings.

Despite these limitations, this study has several important strengths. The paired pre- and post-travel sampling design allowed direct assessment of carriage acquisition associated with pilgrimage travel. In addition, documentation of universal MenACWY vaccination in the cohort enabled clearer interpretation of serogroup-specific carriage patterns in the contemporary vaccination era. Overall, our findings contribute to the understanding of meningococcal carriage dynamics among vaccinated pilgrims participating in large international mass gatherings. The detection of non-MenACWY serogroups, particularly serogroups B and X, after travel suggests that meningococcal epidemiology in pilgrimage settings continues to evolve and highlights the importance of continued surveillance among pilgrims and returning travelers.

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This study has several other limitations that should be considered when interpreting the findings. First, the study was conducted at a single center in Turkey, which can limit generalizability to other pilgrim populations from different geographic or sociodemographic backgrounds. Recruitment from individuals attending pre-travel health assessments may also introduce selection bias, as pilgrims who do not attend such assessments would not have been captured. Regarding methodological limitations, nasopharyngeal swab specimens were collected within 1 to 5 days of return, and any delay in post-travel sampling may have affected carriage detection due to natural clearance. Although standardized PCR-based methods were used for bacterial identification, the absence of culture-based confirmation and detailed molecular characterization such as multilocus sequence typing or clonal complex analysis limits the depth of epidemiological interpretation. Serogroup distribution was therefore analyzed descriptively rather than through genomic surveillance. Behavioral and environmental factors such as crowd exposure, mask use, or hygiene practices during travel were not systematically assessed and may represent sources of unmeasured confounding. Differences in demographic characteristics between Hajj and Umrah participants, particularly age and duration of stay, may also independently influence carriage dynamics. Because the number of carriage events was relatively limited, multivariable modeling was not performed, to avoid unstable estimates, and between-group comparisons should therefore be interpreted cautiously. Future studies incorporating genomic analyses, larger sample sizes, and standardized behavioral data collection could provide deeper insights into transmission dynamics during mass gatherings.

Conclusions

In this cohort of MenACWY-vaccinated Hajj and Umrah participants, meningococcal carriage increased significantly after travel, driven predominantly by acquisition of serogroups B and X. No carriage of vaccine-covered serogroups was detected after travel, which may suggest an effect of MenACWY vaccination, although this study did not assess vaccine effectiveness. These findings underscore the need for continued surveillance of non-vaccine serogroups among pilgrims and returning travelers, and highlight broader vaccination considerations in populations participating in large international mass gatherings.

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Institutions Where Work Was Done

The study was conducted at Eskişehir Osmangazi University Faculty of Medicine and the Eskişehir Provincial Directorate of Health, Eskişehir, Türkiye.

Declaration of Figures' Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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