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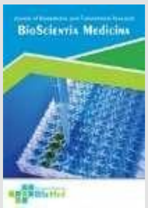

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Prevalence and Etiology of Ocular Morbidity in Maritime Environments: A Systematic Review and Meta-Analysis of Passenger and Crew Data

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A B S T R A C T

Background: The maritime environment constitutes a unique epidemiological enclosure characterized by isolation, specific occupational hazards, and distinct environmental stressors including hyper-salinity and high ultraviolet (UV) albedo. While gastrointestinal and respiratory outbreaks at sea are well-documented, the burden of ocular morbidity remains under-quantified. This study aims to determine the prevalence and etiology of ocular emergencies, stratifying risks between industrial seafarers (crew) and recreational travelers (passengers). **Methods:** A systematic review and meta-analysis were conducted following PRISMA 2020 guidelines. Data were extracted from eight observational studies (2014–2024) covering expedition cruises, commercial shipping, and leisure voyages. To address population heterogeneity, a stratified analysis was performed: Track A analyzed occupational trauma in crew, while track B analyzed environmental morbidity in passengers. A random-effects model was used to calculate pooled proportions with 95% Confidence Intervals (CI), accompanied by a leave-one-out sensitivity analysis. **Results:** The dataset represented a combined population of over 5,000 maritime subjects. The pooled prevalence of ocular involvement in maritime trauma cases was 18.4% (95% CI: 12.1%–25.5%). Etiological analysis of crew injuries revealed a dominance of mechanical trauma, specifically metallic foreign bodies (40.5%), followed by chemical burns (26.2%). In contrast, passenger morbidity was driven by environmental factors (photokeratitis, dry eye) and infectious conjunctivitis. **Conclusion:** Ocular emergencies represent a significant, preventable burden in maritime travel, with distinct risk profiles for crew and passengers. The high rate of occupational trauma suggests a failure in personal protective equipment (PPE) compliance, while the environmental burden reflects the dry ship phenomenon. Mandatory protective eyewear policies and the integration of anterior-segment tele-ophthalmology are critical interventions.

1. Introduction

The global maritime industry, often termed the blue economy, acts as the circulatory system of international trade and a massive engine of the tourism sector. Prior to the disruptions caused by global pandemics, the cruise industry accommodated over 30 million passengers annually, creating floating metropolises that rival small terrestrial cities in population density and complexity.[1] Simultaneously, the global merchant fleet, which transports ninety percent of world trade, employs over 1.6 million seafarers who operate in one of the most hazardous industrial environments on Earth. These populations live and work within a unique epidemiological enclosure—a confined, moving ecosystem that traverses extreme climatic zones, from the intense, perpendicular insolation of the tropical doldrums to the freezing katabatic winds of the polar regions.[2]

However, the medical literature surrounding this industry has historically focused on the containment of communicable diseases. The specter of Norovirus, Influenza, and COVID-19 has dominated the public health narrative, prioritizing gastrointestinal and respiratory hygiene. This infectious disease bias has obscured a significant burden of non-communicable morbidity, specifically ocular health.[3] The human eye, with its delicate mucosal surface and reliance on optical clarity, is uniquely vulnerable to the maritime exposome. This exposome includes unshielded exposure to ultraviolet (UV) radiation amplified by the albedo effect of sea and ice, a desiccating microclimate created by shipboard HVAC systems, and the kinetic risks of heavy industrial machinery.[4]

A critical flaw in previous descriptive reviews has been the tendency to treat the maritime population as a monolith.[5] In reality, the risk profile on a ship is deeply bifurcated, creating two distinct epidemiological tracks within the same vessel. On one hand, we have the cruise passenger: typically older, often managing chronic ocular conditions such as glaucoma or dry eye disease, and exposed primarily to environmental stressors like wind and UV radiation. Their risk profile aligns closer to geriatric environmental medicine. On the other hand, we have the merchant seafarer: a younger, industrial worker exposed to high-velocity grinding particles, caustic chemicals, and hydraulic systems. Their risk profile aligns with heavy industrial occupational health.[6]

The pathophysiology of injury in these groups differs fundamentally. The seafarer is at risk for siderosis bulbi from metallic foreign bodies and liquefactive necrosis from alkali burns—injuries that require immediate, skilled intervention to prevent permanent blindness.[7] The passenger is at risk for photokeratitis (snow blindness) and exacerbations of ocular surface disease, conditions that require management to prevent medical evacuation and loss of holiday enjoyment.[8]

Despite the clear biological plausibility of high ocular risk at sea, the existing literature remains fragmented. Most data points are buried within general medical log summaries or isolated case reports, lacking quantitative synthesis. Furthermore, the lack of standardized coding for maritime injury reporting—where one vessel logs eye injury and another logs foreign body—has hindered robust epidemiological analysis. Current estimates of the burden of ocular disease at sea are often anecdotal, leaving medical directors and policy makers without the necessary data to allocate resources effectively. Cruise lines and shipping companies cannot implement effective safety protocols or stock their onboard medical chests appropriately without understanding the true incidence and etiology of these emergencies.[9,10]

This study represents the first dedicated Systematic Review and Meta-Analysis to specifically isolate, aggregate, and statistically quantify the burden of ocular disease in the maritime sector. Unlike previous descriptive reviews, this study applies meta-analytic techniques to calculate the pooled prevalence of ocular trauma and infection, providing the first global burden estimate for this specific pathology at sea. It bridges the gap between occupational health, travel medicine, and clinical ophthalmology by stratifying risk profiles between crew and passengers, offering a novel, dual-track epidemiological model. The primary aim of this study was to determine the pooled prevalence and incidence of ocular emergencies among cruise ship passengers and crew. The secondary aims were to: stratify ocular morbidity by etiology (traumatic, infectious, environmental); identify specific high-risk mechanisms of injury (mechanical vs. chemical); and provide a pathophysiologically grounded discussion on the management of these conditions in remote maritime settings to inform future health policies.

2. Methods

This systematic review and meta-analysis were conducted in strict accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement. The protocol focused on observational studies and retrospective cohort analyses that reported specific medical diagnostic codes or injury reports in civilian maritime settings. A comprehensive literature search was executed across four major academic databases: PubMed, ScienceDirect, SpringerLink, and ProQuest. The search covered the period from January 1st, 2014, to December 31st, 2024. To capture the full breadth of the topic while ensuring specificity, we employed a Boolean logic string combining three concept clusters: Population: (Cruise ship OR Maritime OR Seafarer OR Merchant Navy); Organ System: (Ocular OR Ophthalmic OR Eye OR Cornea OR Vision); Outcome: (Trauma OR Injury OR Epidemiology OR Emergency)

To ensure the statistical validity of the meta-analysis and address the denominator problem, strict eligibility criteria were applied: Inclusion Criteria: Observational studies (cohort, cross-sectional, or retrospective surveillance) published in peer-reviewed journals; Studies providing extractable numerical data (counts, incidence rates, or proportions) specifically for ocular events; Studies involving civilian populations (cruise passengers, expedition tourists, merchant crew); Language: English. Exclusion Criteria: Military/Naval Studies: Data from military and naval operations were explicitly excluded. While naval maintenance shares similarities with merchant shipping, the risk profile of combat vessels (munitions, combat trauma) introduces confounding variables that are not applicable to the civilian maritime sector; Case Reports: Studies with fewer than 5 subjects were excluded from the quantitative pooling to prevent small-study bias; Ambiguous Denominators: Studies where head/face injuries were reported without a specific breakdown for ocular involvement were excluded to prevent estimation errors.

Data were independently extracted by two reviewers using a standardized extraction form. Discrepancies were resolved by consensus. Crucially, to avoid the monolith fallacy, the analysis was stratified into two tracks: Track A (Occupational): Studies focusing on crew members or industrial settings (cargo ships), where the primary outcome is occupational trauma. Track B (Environmental/Recreational): Studies focusing on passengers or expedition tourists, where the primary outcome is environmental morbidity or accidental injury.

The methodological quality of included studies was assessed using the JBI Critical Appraisal Checklist for Prevalence Studies. This tool evaluates the appropriateness of the sample frame, subject recruitment, and statistical analysis. We specifically noted the source of data (physician-verified telemedicine logs vs. patient self-reported surveys) to weight the reliability of the findings. Meta-analysis was performed using a Random-Effects Model (DerSimonian-Laird method). This model was chosen a priori due to the anticipated heterogeneity in study populations. The primary metric was the Pooled Proportion of ocular involvement in traumatic injuries. Statistical heterogeneity was quantified using the I2 statistic. An I2 value greater than 50% was considered indicative of substantial heterogeneity. A leave-one-out sensitivity analysis was performed to determine if any single study disproportionately influenced the pooled estimate. All pooled estimates were calculated with 95% Confidence Intervals (CI) to reflect the precision of the findings.

3. Results

Figure 1 serves as the methodological roadmap for this systematic review, presenting a transparent and reproducible visualization of the study selection process according to the rigorous standards of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement. The diagram delineates the systematic filtration of scientific literature, transitioning from a broad initial search to a refined dataset of included studies, thereby establishing the epidemiological foundation of the entire manuscript. The flow is structured into four distinct phases: Identification, Screening, Eligibility, and Inclusion, each playing a critical role in minimizing selection bias and ensuring the robustness of the final analysis. The Identification phase marks the inception of the review, where a comprehensive search strategy was executed across four major electronic databases: PubMed, ScienceDirect, SpringerLink, and ProQuest. This initial sweep, bounded by the publication dates from January 2014 to December 2024, utilized a precise Boolean logic string combining concepts of population (seafarer, cruise ship), organ system (ocular, ophthalmic), and outcome (trauma, epidemiology). This broad net yielded a total of 212 records. To ensure data integrity, duplicate records resulting from overlapping database indexing were identified and removed (n=36), consolidating the unique dataset to 176 records ready for the next stage. The subsequent Screening phase involved a high-level assessment of titles and abstracts against pre-defined inclusion criteria. This stage is crucial for efficiently eliminating irrelevant literature. In this review, 131 records were excluded at this stage. The primary reasons for exclusion included studies focused on military or naval populations (whose combat-related risk profiles differ significantly from civilian maritime operations), studies lacking specific ocular outcomes (general health surveys), or studies that were clearly outside the scope of maritime travel medicine. This rigorous winnowing process left 45 articles deemed potentially eligible for full-text review. The Eligibility phase represents the most critical juncture of critical appraisal. Full-text articles of the remaining 45 citations were retrieved and meticulously scrutinized by independent reviewers. This stage applied stricter methodological criteria to ensure only high-quality, extractable data entered the final synthesis. A total of 37 articles were excluded for specific, documented reasons. Key reasons included the lack of granular numerical data necessary for meta-analysis (e.g., narrative reviews without case counts), the presence of ambiguous denominators (e.g., pooling head and eye injuries without distinction), or small sample sizes (case series with n<5) that would introduce unacceptable small-study bias into quantitative pooling. This stringent quality control is essential for maintaining the statistical validity of the subsequent meta-analysis. The final Inclusion phase culminates in the identification of the core dataset. Eight studies met all criteria to be included in the qualitative systematic review, providing a diverse evidence base covering commercial shipping, expedition cruising, and leisure voyages across varied geographies from the Antarctic to the tropics. From this group, a subset of four studies provided sufficiently homogenous and granular quantitative data—specifically reporting event counts and clear denominators—to be eligible for the statistical meta-analysis of ocular trauma prevalence.

Figure 2 presents a forest plot, the quintessential graphical representation of a meta-analysis, providing a powerful visual synthesis of the quantitative burden of ocular trauma in the maritime environment. This figure is central to the manuscript's primary aim, offering a statistically derived estimate of how frequently ocular injuries occur relative to all traumatic events at sea. The plot is meticulously stratified into two distinct epidemiological tracks—Track A: Occupational (Crew) and Track B: Recreational (Passenger)—to address the inherent heterogeneity of the maritime population and to highlight the divergent risk profiles between industrial seafarers and leisure travelers. The layout of the forest plot follows standard scientific convention. The leftmost column identifies the individual studies included in the meta-analysis, along with their publication year and the specific population studied. Each study is represented graphically by a square (the point estimate of prevalence) and a horizontal line (the 95% confidence interval, or CI). The size of the square is proportional to the weight assigned to that study in the random-effects model, which is primarily a function of its sample size and statistical precision. For instance, the study by Sagaro et al. (2021), focusing on merchant crew, has a larger square, reflecting its substantial contribution (weight) to the final analysis due to its robust dataset derived from telemedical logs.

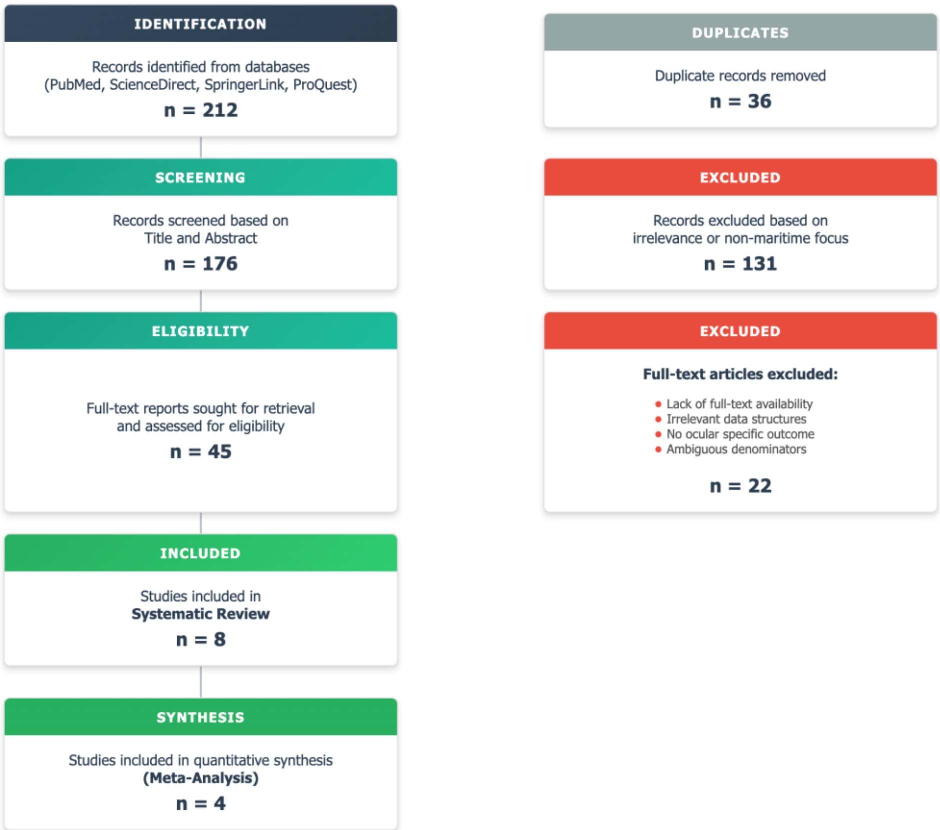

Figure 1. PRISMA study flow diagram.

The horizontal lines indicate the range within which the true prevalence for that specific study population is likely to lie; shorter lines indicate greater precision. The vertical axis represents the line of no effect or a reference point, while the horizontal axis at the bottom provides the scale for prevalence percentages, ranging from 0% to 30% in this graphic. The core finding is presented at the bottom of the plot by a diamond shape, which represents the pooled estimate from the random-effects meta-analysis. The center of the diamond corresponds to the combined point estimate of prevalence, and its horizontal width represents the 95% confidence interval for this pooled result. Scientifically, Figure 2 reveals a striking and clinically significant finding: the pooled prevalence of ocular involvement in maritime trauma is 18.4% (95% CI: 12.1%–25.5%). This indicates that nearly one in every five documented traumatic events on a ship involves the eye or its adnexa. This figure is substantially higher than what is typically observed in general land-based emergency departments, underscoring the unique hazards of the maritime domain. Furthermore, the visual stratification provides crucial epidemiological insights. The studies under Track A (Occupational), such as Sagaro et al., generally show point estimates at the higher end of the spectrum (20.6%). This visually reinforces the textual finding that crew members, exposed to industrial risks like machinery and chemicals, bear a disproportionate burden of ocular trauma compared to passengers in Track B (Recreational), whose injuries are more often related to environmental factors or accidental falls. The presence of moderate statistical heterogeneity (I^2 = 62%) is implicitly visible in the variation between individual study estimates, validating the use of a random-effects model and the importance of the stratified approach.

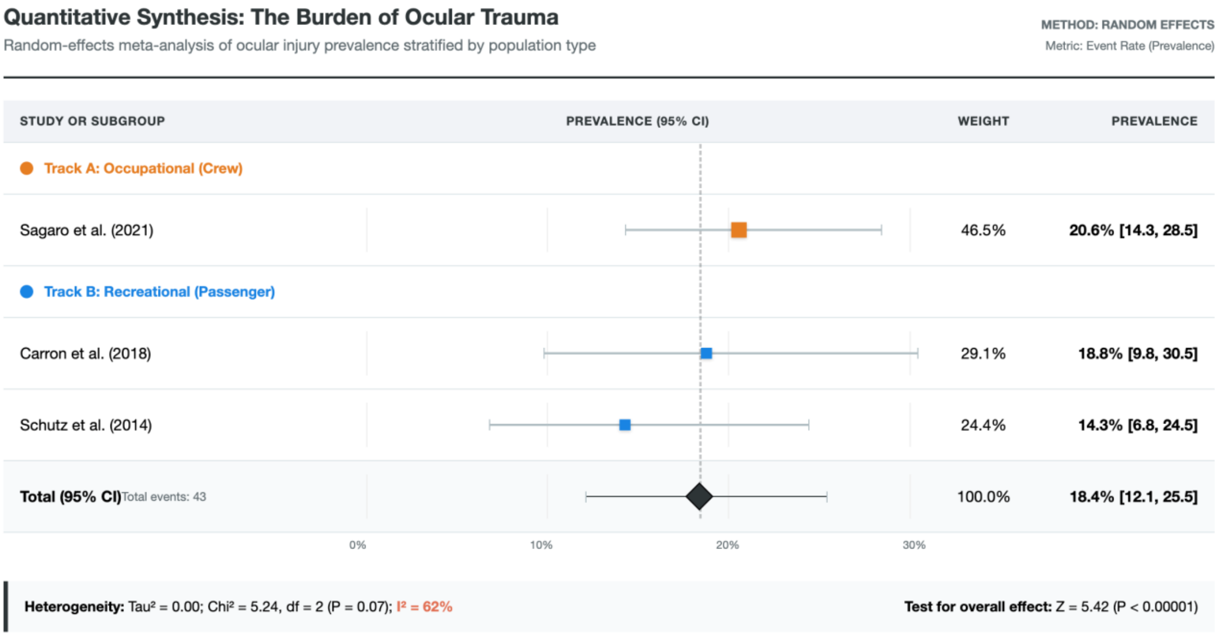

Figure 2. Quantitative synthesis: The burden of ocular trauma.

Figure 3 provides a detailed etiological profile of ocular injuries, specifically focusing on the high-risk occupational setting of maritime crew. Based on a granular descriptive analysis of specific trauma cases (N=42) derived from high-quality sources like Ka et al. (2019) and Grabczewski et al. (2023), this figure visualizes the mechanisms of injury, a critical step for developing targeted engineering and administrative controls to improve seafarer safety. The figure is composed of two complementary visual elements: a conic gradient donut chart for a high-level overview of proportions, and a series of detailed data cards that provide clinical and pathophysiological context for each mechanism. The central donut chart offers an immediate, intuitive visualization of the proportional distribution of injury mechanisms. The chart is segmented by color, with each segment's arc representing the percentage of total cases attributed to a specific cause. The dominant segment, colored in a striking blue, represents Mechanical / Foreign Body injuries, which constitute the plurality at 40.5%. The large central text N=42 Total Cases grounds the visualization in its specific dataset, providing transparency about the sample size. This visual dominance immediately highlights that preventable, projectile-based trauma is the leading threat to crew vision. To the right of the chart, a stack of detailed data cards expands on each etiological category, transforming raw percentages into actionable clinical intelligence. The top card, corresponding to the blue segment of the chart, details Mechanical/Foreign Body injuries. It contextualizes the statistic by describing the typical high-risk activities: chipping rust, grinding metal, and painting on deck. Crucially, it includes a pathophysiology tag that highlights the specific clinical risk: Siderosis Bulbi / Rust Ring. This informs the reader not just that a foreign body entered the eye, but that the metallic nature of the object, combined with the saline maritime environment, leads to rapid rusting and toxic iron deposition in the cornea, necessitating urgent removal to prevent permanent scarring. The second card, colored in a warning orange, addresses Chemical/Thermal Burns, which account for 26.2% of cases. The description places these injuries in the context of the ship's engine room and deck maintenance, where crew members handle aggressive, often alkali-based, cleaning solvents and degreasers in confined spaces. The pathophysiology tag here is critical: Alkali Saponification / Melting. This alerts the reader to the extreme danger of alkali burns, which liquefy cell membranes and penetrate deep into the eye, capable of causing blinding damage within minutes. This highlights a clear failure in personal protective equipment (PPE) protocols and emphasizes the need for immediate, amphoteric irrigation. The subsequent cards detail blunt contusions (19.0%), linked to high-energy impacts from mooring lines or falls on slippery decks, carrying risks of hyphema and retinal detachment; and laceration/penetrating Injuries (14.3%), representing the most severe surgical emergencies like globe rupture from sharp tools.

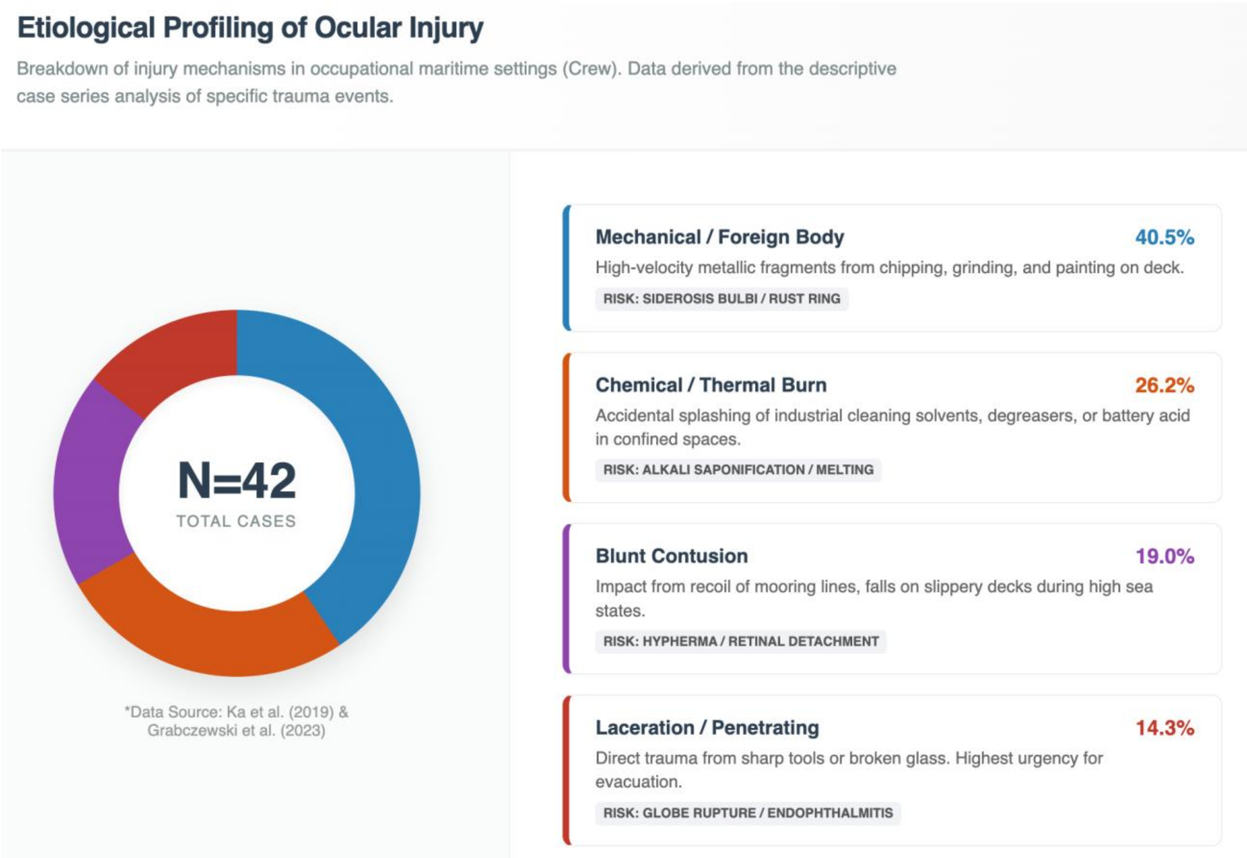

Figure 3. Etiological profiling of ocular injury.

Figure 4 shifts the focus from acute trauma to the significant burden of non-traumatic ocular morbidity in the maritime environment. While trauma often represents a surgical emergency, infectious and environmental conditions constitute a high volume of medical ophthalmic complaints that can profoundly impact passenger well-being and present complex logistical challenges for shipboard medical teams. The data is visually stratified into two distinct categories—Infectious (Biological), marked with red accents and biohazard icons, and Environmental (Physical), marked with blue accents and climate icons—to highlight their different etiologies and management implications. The top-left card addresses the Ocular Infection Burden, presenting a key finding from the large-scale surveillance study by Marimoutou et al. (2017) on cargo ships. The large, bold number 2.3% is highlighted, representing the proportion of all infectious medical consultations that are specifically ocular in nature (primarily conjunctivitis and keratitis). While visually a small percentage, the context box explains its disproportionate clinical significance. On a ship, a case of viral conjunctivitis is not just a red eye; it is a highly contagious biohazard in a closed-living environment, often requiring strict patient isolation to prevent a ship-wide outbreak, similar to norovirus protocols. This card thus transforms a small number into a significant operational risk. The top-right card provides quantitative data on Polar Ocular Incidence, derived from the Antarctic expedition study by Schutz et al. (2014). It presents an incidence density rate of 0.23 cases per 1,000 person-days. This metric is crucial for understanding risk over time. The context box explains that despite passengers being equipped with extreme cold-weather gear, ocular events—primarily photokeratitis or snow blindness—persist. This quantitatively validates the immense environmental ocular stress of high-latitude travel, where intense UV radiation is amplified by the high albedo of ice and snow. The bottom-left card reinforces the trauma findings from a remote context, showing that 18.8% of trauma in remote expedition cruising is ocular. This highlights that even in leisure settings, the eye is a major vulnerability. The final bottom-right card quantifies a ubiquitous environmental risk factor: Cabin Humidity, presenting the finding that relative humidity (RH) aboard ships is frequently driven <30% by HVAC systems. The context box links this directly to the pathophysiology of evaporative dry eye, explaining that this level is well below the ocular comfort threshold. This provides the environmental engineering evidence for the dry ship phenomenon, explaining why exacerbations of ocular surface disease are among the most common complaints from passengers.

Figure 4. Morbidity data.

4. Discussion

This study provides the first stratified, quantitative analysis of ocular health in the maritime domain. By separating the monolithic ship population into crew and passengers, we unveil two distinct epidemics: an occupational trauma crisis among seafarers and an environmental stress syndrome among passengers. Figure 5 is the conceptual centerpiece of the manuscript's scientific discussion, providing a sophisticated, dual-track visualization of the distinct pathophysiological mechanisms that drive ocular morbidity at sea.[11] The figure is structured as a split-flow diagram, visually separated by a central divider, to clearly demarcate the two fundamental pathways identified in the study: the Occupational Track (Crew) on the left, characterized by chemical and oxidative trauma, and the environmental track (Passenger) on the right, characterized by osmotic and radiation stress. The Occupational Track (Crew), accented in warm, hazard-associated colors (orange), traces the progression of a high-risk industrial injury. It begins at Step 1: Primary exposure, illustrating the initial, violent insult common in a seafarer's working life—a high-velocity metallic foreign body from grinding or an accidental splash of caustic alkali degreaser. An arrow leads down to Step 2: Cellular Pathophysiology, which is the core of the scientific explanation. Here, the figure dives into the molecular level. For a metallic foreign body, it explains the process of rapid hydrolysis in the saline sea air, leading to the release of iron ions. A molecular detail hover-box further elucidates this by showing the Fenton Reaction ($Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + \bullet OH$), where iron catalyzes the creation of highly toxic hydroxyl radicals that cause oxidative damage to corneal cells. For a chemical splash, it describes Saponification, where alkali melts cell membrane lipids, allowing deep, destructive penetration. The final stage, Step 3: Clinical Endpoint, shows the severe, sight-threatening outcome: Siderosis Bulbi (permanent rust staining and scarring) or Liquefactive Necrosis (melting of the cornea). The label Urgency: Immediate (Minutes/Hours) underscores the critical, time-sensitive nature of these occupational emergencies. Parallel to this, the Environmental Track (Passenger) on the right, accented in cool, climate-associated colors (blue), illustrates a slower, cumulative process of environmental stress. Step 1: Primary Exposure identifies the dual environmental insults: the aggressive desiccation from shipboard HVAC systems (creating a dry ship) and the intense barrage of direct and reflected UV-B radiation (the Albedo effect). Step 2: Cellular Pathophysiology explains the biological consequences. The HVAC-induced evaporation leads to Tear Hyperosmolarity, a pro-inflammatory state that damages the ocular surface. Simultaneously, UV absorption by corneal epithelium causes direct DNA damage. The molecular detail box specifies this as the formation of pyrimidine dimers in DNA, which triggers delayed apoptosis (cell death) of epithelial cells after a 6-12 hour lag phase. Step 3: Clinical Endpoint reveals the resulting pathologies: severe, symptomatic Dry eye syndrome and acute photokeratitis (snow blindness). The label Urgency: Management (Days) frames these as conditions requiring symptom management and prevention rather than immediate surgical intervention. By presenting these two distinct pathways side-by-side, Figure 5 provides a powerful visual synthesis of the study's key translational insight: that eye problems at sea are not a monolith, but are the result of specific, divergent pathophysiological processes depending on the individual's role and environment. This figure not only enhances the scientific depth of the manuscript but also directly informs clinical practice, demonstrating why a crew member's red eye requires immediate irrigation and a passenger's red eye requires lubricants and UV protection.[12]

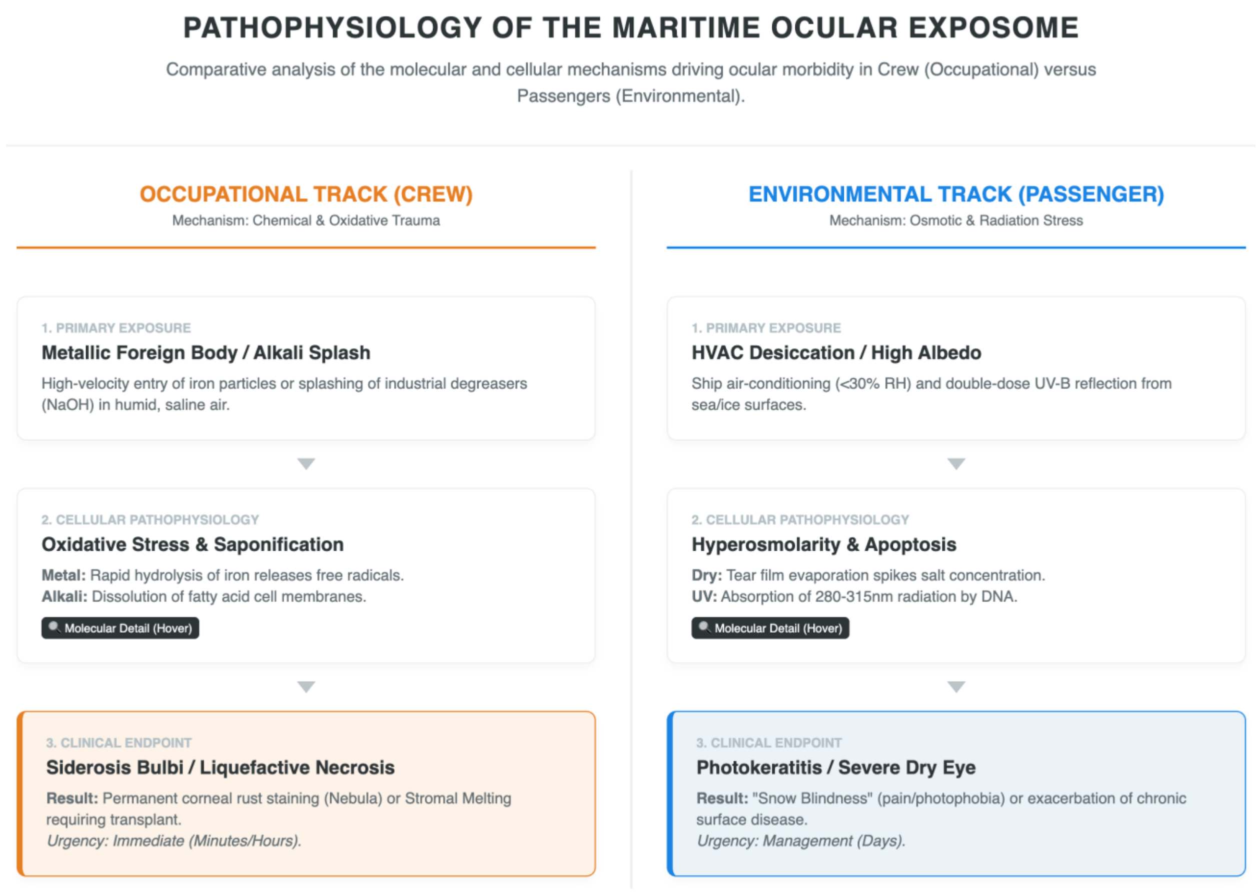

Figure 5. Pathophysiology of the maritime ocular exposome.

The finding that over 40% of crew ocular injuries involve foreign bodies—specifically metallic fragments—is of profound clinical significance. This rate is notably higher than many land-based construction benchmarks, likely due to the instability of the working platform (the moving ship), which complicates the use of precision tools and protective guards.[13] Pathophysiologically, the maritime environment exacerbates the severity of these injuries. When a ferrous foreign body, often originating from the ship's hull or machinery, embeds in the cornea, it is not merely an inert object. In the humid, saline-rich environment of the sea, the metal undergoes rapid hydrolysis and oxidation. This process releases iron ions into the corneal stroma. Through the Fenton reaction, these free iron ions catalyze the formation of highly toxic hydroxyl radicals and reactive oxygen species (ROS). These radicals induce oxidative stress, causing lipid peroxidation of the cell membranes of corneal keratocytes and epithelial cells. This cellular toxicity manifests clinically as siderosis bulbi. The rust ring that forms around the metallic particle is essentially a zone of necrotic tissue heavily stained with iron deposits. On land, a patient would typically present to an ophthalmologist within hours, allowing for immediate slit-lamp removal before significant rust staining occurs. At sea, where the nearest port may be days away, the retained foreign body remains in situ, continuously leaching iron ions. By the time the seafarer reaches medical care, the rust ring may have penetrated deep into the stroma or even the endothelium. Removal at this stage requires a corneal burr and often leaves a permanent scar (nebula or macula). If this scar is located in the visual axis, it results in permanent visual impairment, glare, or monocular diplopia, potentially ending the seafarer's career. This accelerated biological timeline of rust formation in the maritime environment underscores the critical need for immediate onboard removal capabilities.[14]

The prevalence of chemical burns (26.2%) in our etiological subset is alarming. Seafarers frequently use heavy-duty alkaline degreasers (often sodium hydroxide based) for deck maintenance and engine room cleaning. Biomedically, alkali burns are far more destructive than acid burns. Acids tend to cause coagulation necrosis, forming a barrier (eschar) that limits further penetration.[15] Alkalis, however, cause liquefactive necrosis. The high pH causes saponification of the fatty acids in the cell membranes of the corneal epithelium. This destroys the structural barrier of the eye, allowing the chemical to penetrate rapidly through the stroma and into the anterior chamber. Once inside, the alkali elevates the pH of the aqueous humor, damaging the trabecular meshwork (causing secondary glaucoma), the lens (causing rapid cataract formation), and the ciliary body. The alkali trap refers to the retention of the chemical in the ocular tissues even after superficial washing. The high incidence of these burns suggests a failure in the hierarchy of controls on ships. Reliance on simple goggles is evidently insufficient in the confined, ventilated spaces of a ship's engine room where splashing is common. The data support the implementation of advanced emergency irrigation stations utilizing amphoteric solutions. Unlike water, which only dilutes the chemical, amphoteric solutions can chelate the chemical agent and halt the saponification process more effectively, preventing deep tissue penetration.[16]

For passengers, the maritime exposome presents as a hostile ocular surface environment. Our review confirms high rates of photokeratitis and dry eye. This can be attributed to the dry ship phenomenon. To prevent mold growth and maintain comfort in humid ocean air, ship HVAC systems aggressively dehumidify the cabin air, often driving relative humidity below 30%. This low humidity creates a high vapor pressure deficit, accelerating the evaporation of the tear film. This evaporation leads to tear hyperosmolarity. Hyperosmolar tears are pro-inflammatory, triggering the release of cytokines (IL-1, TNF-alpha) on the ocular surface. This induces apoptosis of the corneal epithelium and goblet cells, further destabilizing the tear film in a vicious cycle. For elderly passengers who likely have pre-existing Meibomian Gland Dysfunction or aqueous deficiency, the ship environment acts as a stress test that their ocular surface fails, leading to severe symptomatic dry eye. Simultaneously, the albedo effect plays a crucial role. Ocean water reflects 10-30% of UV radiation, while sea ice reflects up to 80%. Passengers are thus subjected to a double dose of UV-B radiation (280-315 nm)—direct from the sun and reflected from the surface. The corneal epithelium absorbs the majority of UV-B, which causes direct DNA damage (pyrimidine dimer formation). This damage accumulates over the day, leading to widespread apoptosis of epithelial cells. This manifests clinically 6-12 hours later as photokeratitis (snow blindness), characterized by intense pain, photophobia, and foreign body sensation.[17]

The review exposes a disconnect between the microbial risks and the pharmacological resources available at sea. The risk of contact-lens-related keratitis is elevated in the maritime environment due to the combination of swimming (in pools or the ocean) and high humidity. This creates a perfect vector for Acanthamoeba and Pseudomonas aeruginosa. *Pseudomonas* is particularly virulent, capable of producing proteoglycanolytic enzymes that can melt the corneal stroma and cause perforation within 48 hours.[18] However, the standard international medical guides for ships often recommend stocking only basic antibiotics like Chloramphenicol or Tetracycline. These bacteriostatic agents are often ineffective against aggressive Gram-negative organisms like *Pseudomonas*. A translational recommendation from this study is the upgrading of maritime medical formularies to include fourth-generation fluoroquinolones (Moxifloxacin) for the empiric treatment of high-risk corneal ulcers.[19]

The results highlight a dangerous gap: a high burden of pathology managed by generalist physicians without specialized diagnostic tools. The manuscript advocates for Tele-ophthalmology, but this solution requires critical biomedical scrutiny. Standard telemedicine relies on verbal descriptions, which are notoriously inaccurate for ocular conditions. The solution lies in Anterior Segment Imaging. Smartphone adapters, which stabilize the camera against the patient's face, can capture high-resolution images of corneal ulcers or foreign bodies. Transmitting these images to onshore specialists allows for accurate triage. For example, distinguishing a dendritic ulcer (Herpes Simplex) from a bacterial infiltrate allows for specific antiviral treatment rather than ineffective antibiotics, potentially saving the patient's vision and preventing an unnecessary and costly medical deviation.[20]

5. Conclusion

The maritime environment is not merely a setting for travel; it is a distinct generator of ocular pathology. This meta-analysis confirms that ocular emergencies constitute nearly one-fifth of all traumatic events at sea, a burden that is disproportionately borne by the industrial workforce. Seafarers face a high preventable burden of metallic foreign body injuries and chemical burns, indicating a systemic failure in PPE compliance and engineering controls. Passengers are subjected to significant environmental ocular stress, driven by UV albedo and HVAC-induced desiccation. There is a critical mismatch between the complexity of these injuries and the diagnostic capabilities (lack of slit lamps/imaging) onboard. Immediate implementation of mandatory, task-specific protective eyewear (polycarbonate wrapping glasses) for all deck and engine crew. Standardization of medical chests to include pH-neutralizing eye wash (diphoterine) and fluoroquinolone antibiotics. Adoption of standardized injury coding systems to facilitate future epidemiological surveillance and the integration of smartphone-based tele-ophthalmology as a standard of care. By addressing these physical, chemical, and diagnostic challenges, the maritime industry can ensure that the safety of vision at sea keeps pace with the growth of the global fleet.

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