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Etiological Spectrum and Inflammatory Biomarkers in Catheter-Associated Urinary Tract Infections Among Men

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Abstract

Background: Catheter-associated urinary tract infections (CAUTIs) are one of the most prevalent healthcare-associated infections, especially in those that are catheterized over a long period of time. These infections are characterized by diverse microbial etiologies and These infections are characterized by diverse microbial etiologies and pronounced systemic inflammatory responses. and pronounced systemic inflammatory responses.

Objective: The objective of the study was to describe the bacterial profile and assess inflammatory biomarkers in patients with CAUTIs in males.

Methods: A case-control study was performed in Al-Najaf, Iraq that involves 134 male patients diagnosed with confirmed CAUTIs and 80 healthy controls. Urine samples were tested by standard microbiological methods and bacterial identification was done by the use of VITEK 2 system. ECLIA and ELISA were used to measure serum procalcitonin (PCT), interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF-a) and C-reactive protein (CRP) levels. One-way ANOVA and Pearson correlation were used as tools of statistical analysis.

Results:134 isolates were found, with Escherichia coli (28.4) being the most common pathogen, then Staphylococcus aureus (21.6) and Enterococcus spp. (15.7%). There was a general predominance of gram-negative bacteria. There was a significant increase in all inflammatory biomarkers in patients as compared to controls ($p < 0.0001$). Positive correlations were found to be strong between the biomarkers ($r > 0.7$, $p < 0.001$).

Conclusion: In CAUTIs, gram-negative bacteria are the most common pathogens and linked with a strong systemic inflammatory reaction. Combining microbiological profiling with inflammatory biomarkers can contribute to the improvement of diagnostic accuracy and targeted therapeutic approaches.

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Keywords: Catheter-associated urinary tract infection, CAUTI, men, bacterial profile, inflammatory biomarkers, IL-6, TNF-a, CRP, procalcitonin

Introduction

Urinary tract infections (UTIs) represent one of the most common bacterial infections worldwide. with millions of people getting infected each year and causing a tremendous economic cost to health systems worldwide [1]. Specifically, CAUTIs represent a significant portion of health-care-associated infections and are closely linked with extended catheterization, especially in hospitals, which is both microbially diverse and highly inflammatory, thus impacting disease severity and clinical outcomes.

The microbiological characteristics of CAUTIs are diverse and it is mainly composed of Gram-negative bacteria. Examples of common isolates are *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Enterobacter spp.* and *Proteus* mirabilis. In addition, Gram-positive bacteria like *Enterococcus spp*. and *Staphylococcus aureus* also play a significant role in

the infectious burden especially in nosocomial environments [2, 3]. The polymicrobial characteristics of CAUTIs are indicative of the multi-factorial interaction of host-related, environmental exposure, and the healthcare interventions, in particular, the use of indwelling urinary catheters. Molecular studies have demonstrated that microbial dysbiosis and enrichment of opportunistic pathogens (e.g., *E. coli*) and Klebsiella spp. are linked to an increased vulnerability of people to infections and disease development [4].

The CAUTIs pathogenesis has a close relationship with the colonization of the gastrointestinal tract, which in turn leads to adherence to urethra and uroepithelium followed by ascending infection [5]. Urinary catheterization aids this process, leading to local tissue injury and the deposition of host-derived proteins, especially fibrinogen, onto catheter surfaces, on the catheter surfaces. These proteins are adhesion substrates of uropathogens and therefore enhances biofilm formation which is an important determinant that allows bacteria to survive, fight against the immune system and antimicrobial treatment [6, 7].

Host immune response is a key aspect of the pathogenesis of CAUTIs, which is characterized by the concerted action of innate and adaptive immune responses, encompassing the release of pro-inflammatory cytokines, including (IL-6) and (TNF- α), the attraction of immune cells, and the intensification of the inflammatory [8, 9], At the same time, acute-phase proteins like (CRP) are also effective predictors of systemic inflammatory activity [10, 11].

The extent of host-pathogen interaction has been attributed to the higher levels of these inflammatory biomarkers that have been attributed to complicated UTIs and catheter-related infections. Although this immune response is necessary to eliminate pathogens, however, excessive inflammatory activation may lead to tissue damage, persistent infection and adverse clinical outcomes [12, 13]. In addition, different types of bacterial species can affect the extent and the distribution of immune responses, which explains why microbiological and immunological data should be incorporated in the assessment of CAUTIs.

Additional risk factors predisposing patients to infection including urinary obstruction, prostate-related diseases, and the presence of long-term catheterization could also complicate the development of the disease and increase susceptibility to infection [14]. These factors may contribute to the increasing prevalence of antimicrobial resistance among uropathogens making it necessary to design comprehensive diagnostic and therapeutic interventions. It is important to note that studies have shown that inflammation caused by infections is strongly related to oxidative stress, immune dysregulation, and antioxidant dysfunction, which could aggravate the severity and complications of the disease itself [15]. However, limited studies have comprehensively integrated microbiological profiling with systemic inflammatory biomarkers in CAUTIs, particularly in Middle Eastern populations, where epidemiological patterns and antimicrobial resistance profiles may differ substantially.

Since CAUTI is a polymicrobial disease with the inflammatory mediators playing a crucial role, it is necessary to understand the interrelationship between the distribution of bacteria and host immune response in a comprehensive fashion. Thus, this study explored the range of pathogenic bacteria and will evaluate the main inflammatory biomarkers such as PCT, IL-6, TNF-α, and CRP, in the case of catheter-associated UTI in men.

This study provides novel insight into the combined evaluation of microbial patterns and systemic inflammatory biomarkers in CAUTIs among Iraqi male patients.

Patients and Methods

Study Design and Population

This case–control study was conducted between October 2024 and August 2025 in Al-Najaf, Iraq. CAUTI was defined according to the Centers for Disease Control and Prevention (CDC) criteria, including the presence of urinary tract infection symptoms in catheterized patients along with a positive urine culture. A total of 214 male participants were enrolled, and they were of different age groups. Participants were divided into two groups, 134 patients were diagnosed with catheter-associated urinary tract infections (CAUTIs), and 80 apparently healthy individuals served as the control group. Participants were age-matched with the control group to reduce the impact of confounding factors. Antimicrobial susceptibility testing was not performed in this study, as the primary focus was on bacterial identification and inflammatory biomarker evaluation.

Sample Collection

All the participants were sampled under aseptic conditions and were sampled with 3 to 5 mL of venous blood samples. Separating of serum was performed through centrifugation and storing of serum at -20°C awaiting additional immunological examination. Catheterized patients provided urine sample, which was processed to produce microbiological samples in aseptic conditions.

Microbiological Analysis

Samples were inoculated on selective and differential media, such as MacConkey agar and eosin methylene blue (EMB) agar and incubated at 35–37°C for 18–24 hours. Bacterial growth was assessed by the morphology of the colonies, lactose fermentation, and pigmentation.

The initial screening of the bacterial isolates was done by the standard microbiological and biochemical techniques. The identification was ultimately confirmed by the use of automated VITEK 2 system to achieve accurate species-level identification. The analysis focused on the distribution of uropathogens associated with CAUTIs, without detailed molecular characterization of virulence factors or resistance profiles.

Biochemical Characterization

Representative isolates were further identified by standard biochemical tests, such as indole production, urease, citrate utilization and Triple Sugar Iron (TSI) reaction. These tests enabled differentiation among Enterobacteriaceae and facilitated species-level identification where required.

Biomarker Immunological Evaluation

The levels of Serum procalcitonin (PCT, ng/mL) were determined by the electrochemiluminescence immunoassay (ECLIA). (IL-6, pg/mL), (TNF-α, pg/mL) and CRP (mg/L) levels were measured using commercially available enzyme-linked immunosorbent assay according to the manufacturer's instructions. CRP levels >5 mg/L were considered indicative of inflammation, while levels ≥100 mg/L indicated severe infection as a manifestation of high inflammatory response.

Inclusion and Exclusion Criteria.

The inclusion criteria included male patients who had urinary tract infections affecting any part of the urinary system (kidneys, ureters, bladder, or urethra) especially those related to urinary catheterization.

The patients with confounding urogenital conditions (such as acute or chronic prostatitis, prostate cancer, epididymitis, orchitis, or other non-infectious urological conditions) were excluded to guarantee the specificity and validity of the results.

Ethical Considerations

The study protocol was reviewed and approved by the institutional Ethics Committee of Al-Sadr Medical City, Najaf, Iraq. Informed consent was given to all the participants in written form and the sample was then collected and data obtained. The study was conducted under the established human research ethics.

Statistical Analysis

The SPSS software (version 26; IBM Corp., Armonk, NY, USA) was used to perform the statistical analyses. One-way analysis of variance (ANOVA) was used to make group comparisons. The data are reported as the mean standard deviation (SD). Pairwise comparisons were made through Scheffe post hoc test. To evaluate the relationships between inflammatory biomarkers, Pearson correlation coefficient was used by Pearson. The statistical significance was set at 0.05.

Results

1. Distribution of Bacterial Isolates

A total of 134 bacterial isolates were obtained from male patients with catheter-associated urinary tract infections (CAUTIs). The distribution of isolates is summarized in Table 1.

Table 1

Bacterial Isolate	Number of Isolates (n)	Percentage (%)
Escherichia coli	38	28.4
Staphylococcus aureus	29	21.6
Enterococcus spp.	21	15.7
Pseudomonas aeruginosa	17	12.7
Klebsiella pneumoniae	14	10.4
Enterobacter spp.	8	6.0
Proteus mirabilis	7	5.2
Total	134	100

Table 1: illustrates the relative proportions of bacterial isolates. Gram-negative bacteria, including *E. coli*, *P. aeruginosa*, *K. pneumoniae*, *Enterobacter spp*., and *P. mirabilis*, accounted for 62.7% of all isolates, whereas Gram-positive bacteria (*S. aureus* and *Enterococcus spp*.) represented 37.3%.

2. Inflammatory Biomarkers

Serum levels of procalcitonin (PCT), interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF-α), and C-reactive protein (CRP) were measured in both CAUTI patients and healthy controls (Table 2).

Table 2

Biomarker	CAUTI Patients (Mean ± SD)	Controls (Mean ± SD)	p-value
PCT (ng/mL)	2.34 ± 0.45	0.12 ± 0.03	<0.0001
IL-6 (pg/mL)	78.6 ± 15.2	5.4 ± 1.2	<0.0001
TNF-α (pg/mL)	52.3 ± 10.7	4.8 ± 1.0	<0.0001
CRP (mg/L)	112.4 ± 22.6	3.2 ± 0.8	<0.0001

3. Correlation Between Inflammatory Biomarkers

Pearson correlation analysis showed strong positive correlations among the inflammatory biomarkers (Table 3).

Table 3

Biomarkers	r-value	p-value
PCT ↔ IL-6	0.76	<0.001
PCT ↔ TNF-α	0.71	<0.001
PCT ↔ CRP	0.73	<0.001
IL-6 ↔ TNF-α	0.78	<0.001
IL-6 ↔ CRP	0.75	<0.001
TNF-α ↔ CRP	0.72	<0.001

These correlations indicate that systemic inflammation markers rise concurrently in response to infection, supporting the use of a combined biomarker panel for assessing infection severity in CAUTI patients.

Discussion

UTIs are considered to be one of the most widespread types of bacterial infections globally, second only to respiratory infections in terms of prevalence. Catheter-associated urinary tract infections (CAUTIs) are a clinical problem in healthcare facilities due to their association with the prolonged catheterization, the increased heterogeneity of microorganisms, and the increased risk of complications [16]. The current research shows that there is a polymicrobial profile that is mainly composed of Gram-negative bacteria particularly Escherichia coli, followed by *Staphylococcus aureus* and *Enterococcus spp.* The observations are in accordance with the epidemiological trends observed in the world in recent studies [16, 17].

The existence of Gram-negative organisms in the given case is also in line with previous studies, which indicated that the most common causative agents of CAUTIs are Gram-negative organisms, such as E. *coli*, *Klebsiella pneumoniae*, and *Pseudomonas aeruginosa*. This finding can be explained by the increased capacity of these pathogens to attach to uroepithelial cells and adhere to uroepithelial cells and create biofilms on catheter surfaces [19]. The formation of biofilms is one of the most vital virulence factors that increase the persistence and resistance of bacteria to antimicrobial agents, which in turn helps in the persistence of infection and recurrence. The polymicrobial nature of CAUTIs is also supported by the identification of Gram-positive microbes including Staphylococcus aureus and Enterococcus spp. when applied to patients under invasive procedures, which are mostly hospitalized [20].

The Gram-negative bacteria observed in the current study are in line with recent investigations (2022-2025) that indicate that *Escherichia coli*, *Klebsiella pneumoniae*, and

Pseudomonas aeruginosa are the most frequent causes of CAUTIs. Nevertheless, the relatively greater percentage of *Staphylococcus aureus* in the present study might be indicative of the local hospital practice, management of the catheters, and control of the infections.

High concentrations of inflammatory biomarkers in this research can be explained by the long-term catheterization, high bacterial load, and the presence of pathogens able to form biofilms, contributing to the activation of the systemic immune. Moreover, geographical disparities in the health care environment, late diagnosis, and possible misuse of antimicrobials can also lead to an enhanced inflammatory response.

A key finding of this study was that the inflammatory biomarkers, such as procalcitonin (PCT), (IL-6), (TNF-a) and C-reactive protein (CRP) in patients were significantly higher than in healthy controls. These results correspond to the literature findings that have shown that CAUTIs are linked to a drastic systemic inflammatory response [21, 22]. PCT is one of these biomarkers that has come out as a very sensitive and specific indicator of bacterial infection especially in the differentiation of localized UTIs and systemic infections like urosepsis [23].

The high PCT levels in the given study can be explained by the high level of production of pro-inflammatory cytokines, especially IL-6 and TNF-a, in reaction to bacterial endotoxins. These cytokines promote extra-thyroidal production of PCT, which is an appropriate indicator of overall bacterial load and early sepsis [24]. A number of research studies have indicated that PCT beats conventional inflammatory biomarkers, like CRP, in measuring the severity of infections and how to administer antimicrobial treatment in complicated UTIs [25].

Moreover, high levels of IL-6 and TNF-a are important because they represent a key position in host immunology in the fight against bacteria. TNF-α plays a key role in early inflammatory mediating factors; it enhances the recruitment of leukocytes, amplifies vascular permeability and activates downstream immune signaling networks. TNF-a works in synergy with IL-6 to enhance the effects of inflammatory response and to coordinate both innate and adaptive immunity [26, 27]. High concentrations of these cytokines have been linked with serious infections and poor clinical outcome in patients with CAUTIs [28].

The urinary catheters are also significant in increasing the microbial colonization and the inflammatory reactions. Catheters serve as foreign objects that enable the adhesion of bacteria and the formation of biofilms to help the pathogen find a niche and remain inactive [29]. This long-term colonization leads to long-term immune stimulation and release of cytokines, which could potentially cause tissue damage and severity of the disease. This observation is in agreement with other research reports that show that long-term catheterization is directly correlated with the risk of infections and the inflammatory burden [30].

Besides, patient CRP levels were significantly elevated, which is why it should be considered as an acute-phase biomarker of systemic inflammation. CRP is primarily produced by the liver in response to IL-6 during systemic inflammation and demonstrates the general inflammatory condition of the host [31]. Despite being less specific in comparison to PCT, CRP remains a widely accessible and clinically useful biomarker in clinical practice as a method of measuring disease severity and tracking treatment response [32] All these results underscore the intricate relationships between CAUTI microbial diversity and host immune responses. The prevalence of Gram-negative bacteria and the inflammatory biomarkers are very high, and this points to the importance of integrating microbiological and immunological tests in the management of such infections. This plan is capable of contributing to the timely diagnosis, the specific antimicrobial therapy, and reduction of the risk of complications in the catheterized men. The implications of these findings in clinical practice could be significant in the early diagnosis and risk stratification of patients on catheters.

Conclusion

This paper presents strong evidence that CAUTIs are marked by the polymicrobial etiology and a strong systemic inflammatory response. Microbiological profiling combined with inflammatory biomarker measurement could greatly improve the accuracy of diagnosis, early risk stratification, and guide the design of specific therapeutic interventions in patients with catheterization.

Study Limitations

- The study was conducted in a single geographic region (Al-Najaf, Iraq), which may limit generalizability.
- Only male patients were included, and gender-specific differences were not assessed.
- Molecular characterization of bacterial virulence factors and antimicrobial resistance profiles was beyond the scope of this study.
- Additionally, the cross-sectional study design limits the ability to establish causal relationships between microbial patterns and inflammatory responses.

Future Directions: Future studies ought to examine multi-centers (larger sample) cohorts, involve female patients, and incorporate antimicrobial susceptibility profiling in order to maximize clinical management approaches to CAUTIs.

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