Research Square

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Impact of Temperature and Humidity on Periprosthetic Joint Infections Following Total Knee Arthroplasty: A 12-Year Study in a Mediterranean Climate

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Research Article

Keywords: Periprosthetic Joint Infection, Total Knee Arthroplasty, Seasonal Variations, Temperature, Humidity, Risk Factors

Posted Date: May 9th, 2025

DOI: https://doi.org/10.21203/rs.3.rs-6536892/v1

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Additional Declarations: No competing interests reported.

Abstract

Purpose: This study aimed to examine the influence of temperature, humidity, and seasonal trends on periprosthetic joint infections (PJI) following total knee arthroplasty (TKA) over a 12-year period in a Mediterranean climate.

Methods: A retrospective cohort study was conducted on 5520 patients who underwent TKA between January 1, 2011, and December 31, 2022. Data were collected on patient demographics, surgical details, and PJI incidence, which were defined by Musculoskeletal Infection Society (MSIS) criteria. Meteorological data on daily average temperature and relative humidity were obtained for the same period. Statistical analyses were performed to assess the associations between PJI incidence, seasonal variations, temperature, and humidity.

Results: The overall incidence of PJI was 1.4%, with a significant downward trend over the 12 years (β coefficient= -0.115; p = 0.011). The highest PJI incidence (2%) was observed in winter, but no significant association was found between PJI incidence and seasonal variations (p = 0.080). The temperature range ≤5°C had the highest PJI rate (6.7%), while the 20-25°C range showed the lowest rate (0.4%). No significant effect of humidity levels on PJI incidence was identified (p=0.174).

Conclusion: The study demonstrates a general decline in PJI incidence over time and suggests that colder temperatures are associated with higher PJI rates, with ≤5°C posing the most significant risk. However, humidity and seasonal variations did not significantly influence infection rates. These findings underscore the importance of considering environmental factors like temperature when planning TKA procedures, particularly in regions with Mediterranean climates.

Level of evidence: Level III, Retrospective cohort study

1. Introduction

Periprosthetic joint infection (PJI) is among the most severe complications following total knee arthroplasty (TKA), leading to increased morbidity, functional impairment, prolonged hospitalization, and additional surgical interventions. Despite advancements in surgical techniques and perioperative care, the incidence of PJI remains a challenge, with rates reported between 0.4% and 3.9% [1]. Understanding the factors contributing to PJI is essential for improving patient outcomes and reducing the burden of infection-related complications [2].

Several previous studies have explored the relationship between seasonality and PJI rates following total joint arthroplasty (TJA), yet the results remain inconsistent (**Table 1**) [3-16]. Some have identified higher infection rates during warmer months [3, 6, 8, 14, 15], while others have found no significant seasonal variations [4, 10, 11, 12, 13, 16]. Moreover, a limited number of studies have documented elevated infection rates during the winter season [5, 9]. These inconsistencies may stem from methodological shortcomings such as short study durations, use of various infection definitions, heterogeneous patient

populations, large nationwide registry data without accounting for regional climatic differences, lack of time-series analysis, and the absence of detailed meteorological data analysis such as temperature and humidity. Despite the growing body of literature, further studies are obviously needed to clarify the potential influence of seasonality on PJI rates, particularly in specific climate regions.

To address these gaps, this retrospective cohort study aims to investigate the potential impact of seasonal variations on PJI rates following TKA in a Mediterranean climate. The primary hypothesis of this study is that the incidence of PJI will increase during the hot and humid seasons. By utilizing a 12-year dataset and incorporating time-series regression models, this study seeks to identify seasonal trends and explore the role of temperature and humidity in influencing infection rates. To our knowledge, this is the first study to examine the seasonality of PJI in a Mediterranean climate, and the results may provide valuable insights into infection prevention strategies tailored to specific climatic conditions.

2. Materials and methods

2.1. Study Design and Participants

A retrospective review was conducted to identify all patients who underwent primary total knee arthroplasty (TKA) at the authors' institution between January 1, 2011, and December 31, 2022. A total of 5520 TKA procedures were performed over the 12 years. Periprosthetic joint infection (PJI) was defined based on the criteria established by the Musculoskeletal Infection Society (MSIS) and included patients who required repeat surgical interventions, such as arthrotomy for irrigation and debridement, polyethylene exchange, or single or two-stage revision surgery [17]. Superficial wound complications such as seromas, stitch abscesses, and cellulitis were excluded from the PJI definition. The study population was limited to patients with at least one year of follow-up.

This study was conducted in accordance with the principles of the Declaration of Helsinki and Good Clinical Practice guidelines. Ethical approval was obtained from the institutional review board of the Antalya Training and Research Hospital Ethics Committee (Date and Issue: 14.12.2023 – 17/2). Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines were followed in this study [18].

2.2. Data collection

Hospital records were reviewed to extract patient demographics, date of primary TKA, discharge date, and details of any subsequent PJI-related procedures were collected from the hospital's electronic medical records system. Culture results and identified microorganisms were also documented for PJI cases.

2.3. Season classification and meteorologic data

The study was conducted at a university hospital in Antalya on the Mediterranean coast of Türkiye, located at approximately 36° 53' North latitude and 30° 42' East longitude, with an altitude of 39 meters.

The region experiences a Mediterranean climate, characterized by hot, dry summers and mild, rainy winters (**Figure 1**). Meteorological data, including daily average relative humidity and temperature, were obtained from the Turkish State Meteorological Service for the Antalya region from 2011 to 2022. Seasons were defined as Winter (December-January-February), Spring (March-April-May), Summer (June-July-August), and Autumn (September-October-November).

The daily average temperature values were classified into five-degree increments. Accordingly, the temperatures are classified into seven discrete categories, as follows: below 5 °C, 5-10 °C, 10-15 °C, 15-20 °C, 20-25 °C, 25-30 °C, and 30-35 °C [19, 20]. Daily mean relative humidity (RH) values were classified into three categories, as reported by previous literature, as follows: Relative humidity (RH) values of less than 50% indicate low humidity, while RH values between 50% and 80% indicate medium humidity and RH values of 80% or greater indicate high humidity [21].

2.4. Statistical analysis

All statistical analyses were performed using SPSS version 25.0 (IBM Corp., Armonk, NY). The normality of continuous variables was assessed both visually (histograms and probability plots) and analytically (Kolmogorov-Smirnov test). Descriptive statistics were reported as counts, percentages, means with standard deviations, and medians with ranges (minimum; maximum). Independent samples t-tests were used to compare normally distributed variables, while the Mann-Whitney U test was used for non-normally distributed variables. Categorical variables were compared using chi-squared tests. The models established using linear regression analysis were used to evaluate whether the changes in PJI incidence were statistically significant and whether they exhibited a linear trend. Multivariate logistic regression analysis was conducted to evaluate the effect of temperature ranges and humidity levels on the risk of PJI. Statistical significance was defined as a p-value of less than 0.05.

3. Results

3.1. Demographic data and microbiological profile

A total of 5520 primary TKA patients with a mean age of 67.2±7.7 years (range, 23-94) were evaluated over a 12-year period. There were 952 (17.2%) male and 4568 (82.8%) female patients. Of the total number of patients, 1,198 (21.7%) underwent simultaneous bilateral TKA, while the remaining 4,322 (78.3%) patients underwent single-stage TKA. During the course of the study, 78 patients (1.4%) were identified as having PJI that met the established criteria. The demographic data are presented in **Table 2.**

The median time to PJI detection following TKA was 63.5 days, with a range spanning from 7 to 364 days. Among the PJI cases, 12.8% (n=10) were identified within the first 30 days postoperatively, 32.1% (n=25) between 31 and 60 days, and 23.1% (n=18) between 61 and 90 days. Notably, 67.9% (n=53) of PJI cases were diagnosed within the first three months after surgery. **Table 3** outlines the culture results for patients diagnosed with PJI. Despite meeting the MSIS criteria for PJI, no bacterial growth was observed

in 41 patients. Among the culture-positive cases, the most commonly identified pathogens were *Staphylococcus aureus* (24.3%), *Staphylococcus epidermidis* (21.6%), coagulase-negative staphylococci (13.5%), and *Staphylococcus hemolyticus* (13.5%).

3.2. PJI incidence by years

The incidence of PJI was 1.56% in 2011, reached a peak of 2.49% in 2013, and exhibited fluctuations over the subsequent years, with a notable decline to 0.96% in 2014 and an increase to 1.92% in 2015. In 2017 and 2018, the rates were 0.99% and 1.33%, respectively, before declining to 1.06% in 2020, 0.66% in 2021, and 0.57% in 2022. The results of the linear regression analysis indicated a statistically significant downward trend in PJI incidence, with an annual decrease of 0.115% (β coefficient= -0.115, p = 0.011; Adjusted R^2 = 0.443) (**Figure 2).**

3.3. PJI incidence by months

PJI prevalence was 1.86% in January, peaking at 2.18% in February before dropping to 1.41% in March. Incidence rates were 1.20% in April, 1.47% in May, and 1.09% in June. July and August saw rates of 1.73% and 1.59%, while September marked a low of 0.63%. The lowest incidence occurred in October at 0.24%, followed by increases to 1.14% in November and 1.95% in December. Linear regression analysis showed that monthly changes in PJI incidence were statistically insignificant (β coefficient= -0.065, p=0.176; Adjusted R^2 = 0.092) (**Figure 3).**

3.4. PJI incidence by seasons

The incidence of PJI was highest in winter (2%), followed by summer (1.46%), spring (1.36%), and fall (0.74%). Linear regression analysis revealed no statistically significant relationship between seasons and PJI incidence (β coefficient= -36.8, p=0.080; Adjusted R^2 = 0,770) (**Figure 4**).

3.5. PJI incidence by the mean daily temperature and relative humidity

A categorization of the data according to 5°C increments of daily average temperature at the time of TKA revealed that the temperature range with the highest incidence of PJI was ≤5°C (6.7%). The incidence of PJI in this range was significantly higher than in other temperature ranges (p=0.007). Furthermore, the incidence of PJI was 2.4% in the >5-10°C range, 1.7% in the >10-15°C range, 1.4% in the >15-20°C range, 1.3% in the >25-30°C range, and 2.3% in the >30-35°C range (**Figure 5**). The incidence of PJI according to temperature ranges has not shown a linear trend (B coefficient = -0.671; p-value = 0.128, R^2 = 0.400). In Figure 5, the data is shown with a non-linear trend using a polynomial trend line. The lowest incidence of PJI was observed in the >20-25°C range, at 0.4%. With regard to humidity, the incidence of PJI was 1.5% in low humidity, 1.2% in moderate humidity, and 2.1% in high humidity. However, no significant difference in PJI incidence was identified based on humidity levels (p=0.174) (**Figure 6**) (**Table 4**).

Table 5 presents the multivariate logistic regression analysis of daily mean temperature ranges and humidity categories as predictors of PJI risk following TKA. The temperature range of 20-25 °C, which

has been identified as the lowest incidence of infection, was selected as the reference point. The mean temperature was observed to significantly elevate the risk of infection, particularly at ≤5 °C, compared to other temperature ranges (OR=18.4, 95% CI=3.1-109.2, p=0.001). Furthermore, in the temperature range of 5-10 °C, the odds ratio (OR) was 5.9 (95% CI=1.6-22.8; p = 0.009), in the range of 10-15 °C, the OR was 4.0 (95% CI, 1.4-11.6; p = 0.010), in the range of 15-20 °C, the OR was 3.4 (95% CI=1.2-9.9, p=0.026), in the range of 25-30 °C, the OR was 3.3 (95% CI=1.1-10.3, p=0.044), and in the temperature range of 30-35 °C, the OR was 5.6 (95% CI=1.7-21.4, p=0.006), respectively. With regard to humidity level, there was no statistically significant effect of moderate or high humidity levels on PJI, as compared to low humidity levels, which were selected as the reference category.

4. Discussion

Despite advances in surgical techniques and perioperative care, PJI remains a serious complication following TKA. Thus, identifying factors that influence its occurrence is critical for improving patient outcomes. This study is the first to investigate the impact of seasonal variations, temperature, and humidity on PJI incidence within a Mediterranean climate, where temperature and humidity exhibit notable fluctuations. The findings of this study indicate a statistically significant correlation between lower temperatures and elevated rates of PJI. The highest incidence of PJI was observed during the winter months and at temperatures below 5°C. Conversely, the lowest rates of PJI were observed in the 20-25°C range, indicating that this temperature range may be optimal for minimizing infection risk. In light of these findings, it may be advisable to schedule elective TKA procedures during milder seasons or within the optimal temperature range to reduce the likelihood of infection. However, no significant correlation was identified between humidity levels and PJI incidence, indicating that temperature may exert a more pronounced influence on infection rates in this climate. These findings highlight the necessity of developing infection prevention strategies tailored to specific climatic conditions, particularly in regions with distinct seasonal patterns.

Fourteen prior studies have explored the connection between seasonality and PJI (Table 1) [3-16]. However, their findings have been mixed, with differing conclusions about the impact of seasonal variations on PJI rates. Some studies have found no significant association between seasonality and PJI incidence. In contrast, others have found a higher risk of infection during the summer or, as in the present study, during the winter months. It is crucial to evaluate a number of pivotal elements when analyzing the divergent findings across these studies. The discrepancies between these studies can be attributed to a multitude of factors. First, many of these studies combined different types of arthroplasty procedures, such as total knee arthroplasty (TKA), unicondylar knee arthroplasty (UKA), total hip arthroplasty (THA), and revision surgeries, into a single analysis [3, 7, 10, 11, 14, 15]. This grouping could affect the results since infection rates vary significantly between these procedures. For example, revision surgeries are generally associated with higher infection rates than primary procedures, which may skew the overall findings when analyzed together [22]. Second, variations in how infections are defined across studies have introduced inconsistencies. Surgical site infections (SSIs), such as cellulitis or wound dehiscence, which do not meet the contemporary definition of PJI, were also included [7, 9, 13, 14]. This

broader inclusion may inflate infection rates in certain studies, making it difficult to compare results across the literature directly. Furthermore, the post-surgery timeframe used to measure infections varies widely between studies. Some studies evaluate infections within 30 days of surgery [4, 7], others within 90 days [3, 5], while some extend the tracking period to 12 months [6, 8], further complicating comparisons. Another issue is the variability in study durations, with some investigations lasting only a year [3], while others extend over several years or even decades [8, 10]. Shorter study periods may not accurately capture long-term climatic trends, potentially overlooking subtle seasonal effects. Additionally, many studies utilize large national registry data, particularly in countries like the U.S. and Australia [5-7]. While such data increase statistical power, they also introduce limitations due to the wide geographic coverage. These countries encompass diverse climate zones, from tropical to continental, making it difficult to draw conclusions about seasonality that apply uniformly across such varied environments. Defining seasons and climate adds further complexity, as the timing and characteristics of seasons can differ between regions. For instance, winter temperatures in a tropical climate may resemble spring or summer conditions in a temperate climate, complicating direct comparisons. Only four studies have provided specific data on actual daily temperature and humidity levels [8, 11, 14, 16], which are critical for understanding the environmental factors influencing infection rates. Without this detailed meteorological data, studies that rely solely on calendar-based seasonal definitions may produce misleading or non-generalizable results. While these studies have contributed to our understanding of the relationship between seasonality and PJI, it is essential to consider the aforementioned issues when interpreting the results.

Several strengths of the current study address fundamental limitations commonly seen in previous research on PJI. First, the focus was solely on TKA, excluding other procedures like THA and revisions, ensuring a more precise evaluation of infection rates specific to TKA without confounding by different surgical types. A notable strength is using MSIS criteria to define PJI, which included only true PJI cases while excluding superficial wound issues such as cellulitis or dehiscence. This ensures a more accurate and consistent assessment of PJI incidence compared to earlier studies. The 12-year study period also provides a robust timeframe for capturing long-term seasonal and climatic trends, allowing a more comprehensive analysis than studies of shorter duration. Conducting the study within a single Mediterranean region further reduces the confounding effects of climate variability seen in national registry data from larger, more diverse regions. Lastly, using actual daily temperature and humidity data, rather than relying on calendar-based seasons, strengthens the analysis of environmental impacts on PJI risk. This approach provides more precise, region-specific insights into how environmental conditions influence infection rates.

The relationship between environmental factors such as temperature and humidity and periprosthetic joint infections (PJI) is not fully understood. The development of PJI is multifactorial, and it is certainly not possible to explain it solely through environmental conditions. However, studies reporting an increased risk of PJI with rising temperatures and humidity have proposed several plausible theories. The increased rates of PJI during hot weather are primarily attributed to environmental and physiological factors that promote bacterial growth and elevate the risk of contamination. Warmer temperatures,

especially those exceeding 30°C, and higher humidity levels create ideal conditions for the proliferation of bacteria such as Staphylococcus aureus, a common cause of PJI [23]. Higher temperatures also increase perspiration, raising skin moisture levels and facilitating bacterial growth. Sweating compromises skin sterility and may disrupt surgical sterility, thereby increasing the risk of infection [24, 25]. Our study found that the lowest infection rate occurred within the temperature range of 20-25°C, which aligns with the thermal comfort zone for humans [26, 27]. This range, where sweating is minimized and individuals tend to feel most comfortable, corresponds to the fall season in the Mediterranean climate.

Conversely, studies reporting increased PJI risk during colder months have also proposed theories to support their findings. Sodhi et al. proposed that the prevalence of respiratory infections, such as pneumonia, which are more common in colder months and can raise the risk of postoperative complications, including PJI [9]. Indoor heating during the winter can lower humidity levels, leading to drier skin and mucous membranes, which may increase bacterial entry [28]. Furthermore, patients tend to stay indoors more during colder months, heightening exposure to respiratory pathogens that weaken the immune system and increase overall infection risk. Another explanation for the increased infection risk in winter is the potential compromise of immune function. Colder months often bring reduced sunlight exposure and lower levels of vitamin D, both of which are essential for proper immune regulation. In a recent study, Vit D supplementation following TKA was associated with decreased risk of SSI [29]. However, these theories require further investigation and supporting evidence. The intricate interplay of PJI risk factors complicates their explanation and understanding.

This study has several limitations that should be considered when interpreting the findings. First, as a retrospective cohort study, it is inherently vulnerable to potential biases, including selection and information bias. The reliance on hospital records and electronic medical data may have led to incomplete or inaccurate data collection, particularly in cases where detailed documentation was insufficient. Second, while the study focused on a specific geographic region with a Mediterranean climate, the results may not directly apply to other climates or healthcare settings. Variations in climate, healthcare infrastructure, and patient populations across different regions could influence PJI incidence and seasonal trends, limiting the generalizability of these findings. Therefore, caution is needed when extrapolating these results to other contexts. Third, the study defined PJI using the criteria established by the MSIS, which is based primarily on clinical, laboratory, and microbiological parameters. However, the exclusion of superficial wound complications from the PJI definition may have resulted in an underestimation of infection rates, especially in cases where infections were mild or did not meet the MSIS criteria. Additionally, the high percentage of culture-negative cases (52.6%) underscores the difficulty of accurately diagnosing PJI and may have impacted the reported distribution of causative microorganisms. Fourth, the meteorological data used were drawn from a single location, potentially overlooking microclimatic variations experienced by patients in different parts of the region. Moreover, the study did not account for individual patient-level factors such as socioeconomic status, smoking, obesity, or comorbidities, which could also affect PJI risk and confound the relationship between seasonality and infection rates. Finally, while the study included a 12-year dataset, the relatively small

number of PJI cases (n:78) limits the statistical power to detect subtle seasonal effects. Larger, multicenter studies with more comprehensive data collection and longer follow-up periods may be necessary further to clarify the impact of seasonality on PJI risk. Despite these limitations, this study provides valuable insights into PJI trends in a Mediterranean climate, contributing to the growing body of literature on infection prevention and management in TKA. These findings are particularly relevant to countries experiencing Mediterranean climate, including Spain, Italy, Greece, Turkey, Morocco, Tunisia, Algeria, Syria, Lebanon, Israel, parts of California, and Australia, representing approximately 350 million people.

5. Conclusion

In conclusion, our study provides valuable insights into the seasonal patterns of PJI in a Mediterranean climate, demonstrating that colder temperatures, particularly those below 5°C, are associated with a higher risk of infection. These findings suggest that temperature, rather than humidity, plays a more critical role in influencing PJI rates, and that moderate temperatures may be optimal for minimizing infection risk. Future research should focus on region-specific analyses and incorporate detailed environmental data to develop more targeted infection prevention strategies.

Abbreviations

CI: Confidence Interval

MSIS: Musculoskeletal Infection Society

OR: Odds Ratio

PJI: Periprosthetic Joint Infection

RH: Relative Humidity

ROC: Receiver Operating Characteristics

SPSS: Statistical Package for the Social Sciences

STROBE: Strengthening the Reporting of Observational Studies in Epidemiology

THA: Total Hip Arthroplasty

TJA: Total Joint Arthroplasty

TKA: Total Knee Arthroplasty

UKA: Unicondylar Knee Arthroplasty

Vit D: Vitamin D

Declarations

Funding: No funds have been received for this study.

Ethical approval: Institutional review board approved the study protocol (Date/Issue: 14.12.2023 – 17/2)

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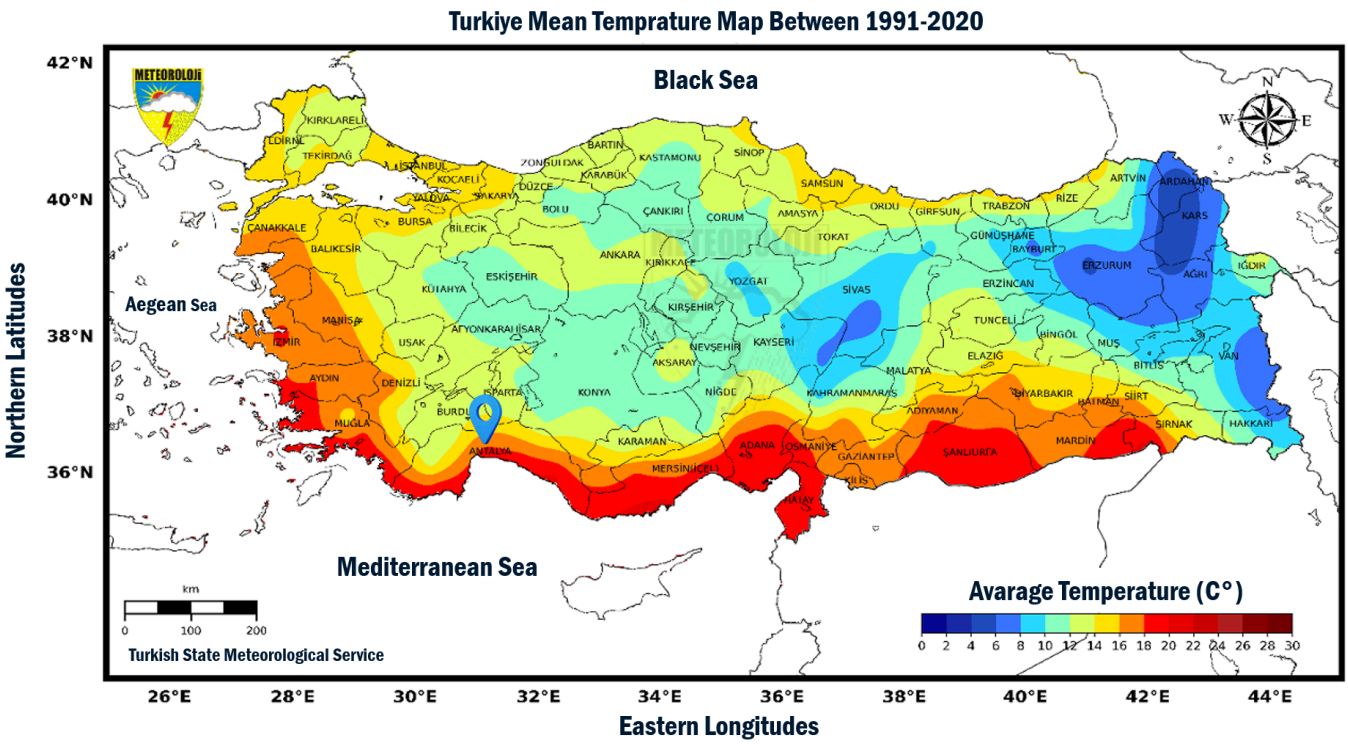
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Tables

Table 1 to 5 are available in the Supplementary Files section.

Figures



Climate data for Antalya (1991–2020, extremes 1930–2023)													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Daily mean °C (°F)	9.8 (49.6)	10.8 (51.4)	13.1 (55.6)	16.4 (61.5)	20.9 (69.6)	25.7 (78.3)	28.9 (84.0)	29.0 (84.2)	25.6 (78.1)	20.9 (69.6)	15.3 (59.5)	11.4 (52.5)	19.0 (66.2)
Average relative humidity (%)	65.8	64.8	65.4	67.4	66.8	59.6	58.0	59.7	59.7	60.4	63.6	68.0	63.3

Figure 1

Mean temperature map of Turkey between 1991-2020. The map shows average temperatures across various regions, with the Mediterranean coastal areas experiencing the highest temperatures, especially during summer. Data is provided by the Turkish State Meteorological Service.

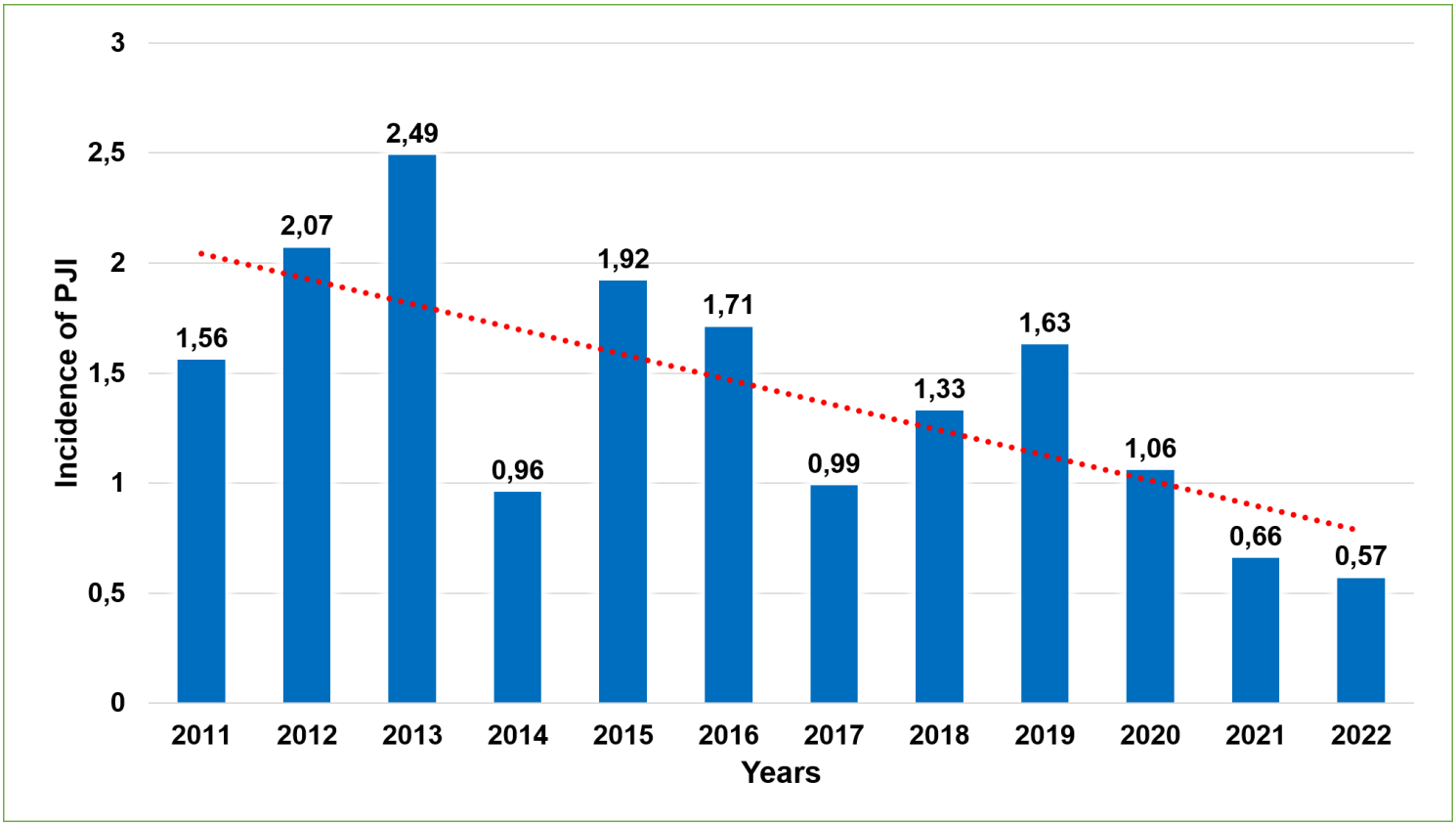


Figure 2

Incidence of periprosthetic joint infections (PJI) from 2011 to 2022. The bar graph illustrates a general decline in PJI incidence, peaking in 2013 and 2015. A trendline indicates a statistically significant decrease in infection rates during the study period.

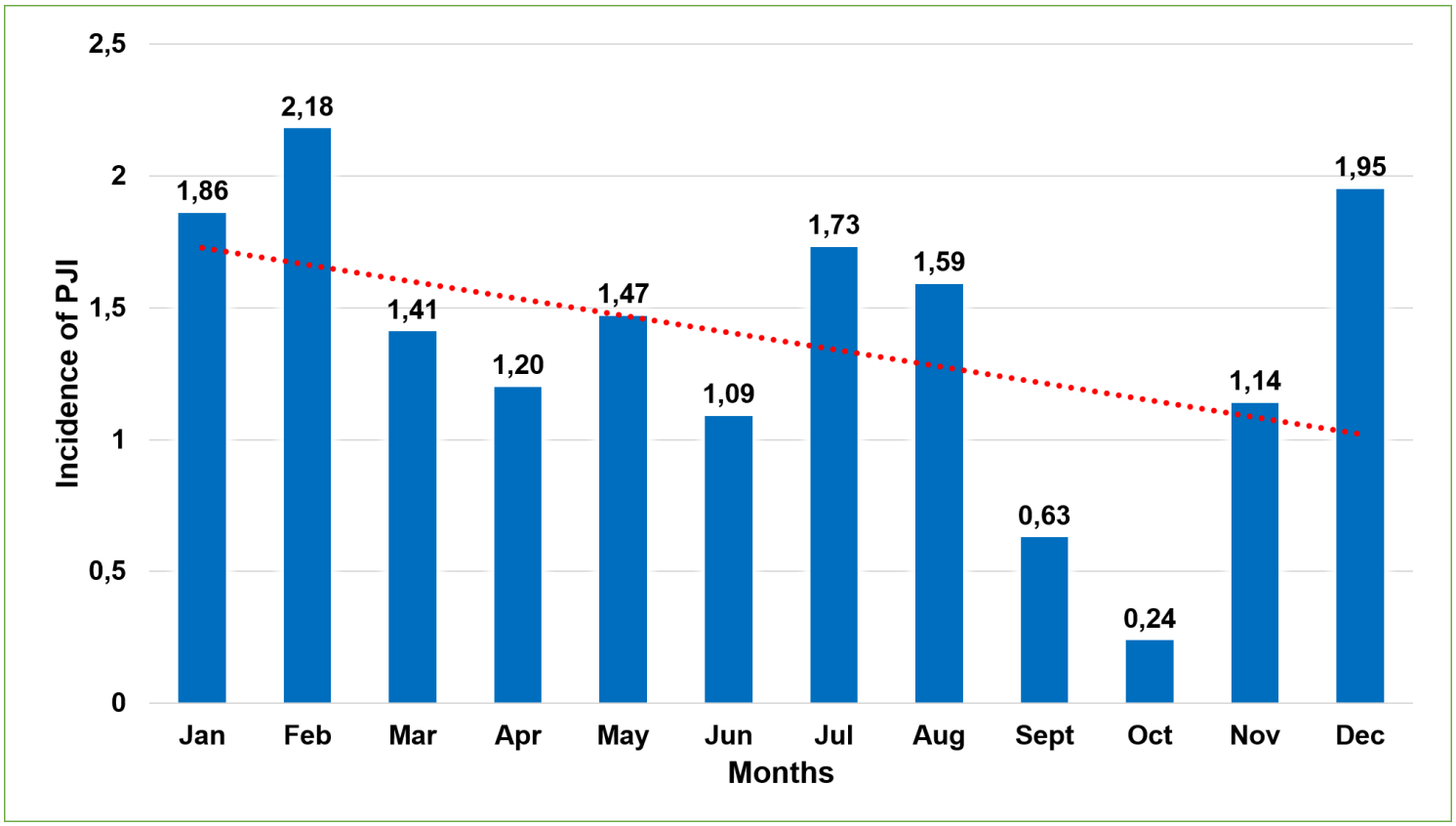


Figure 3

Monthly distribution of PJI incidence.

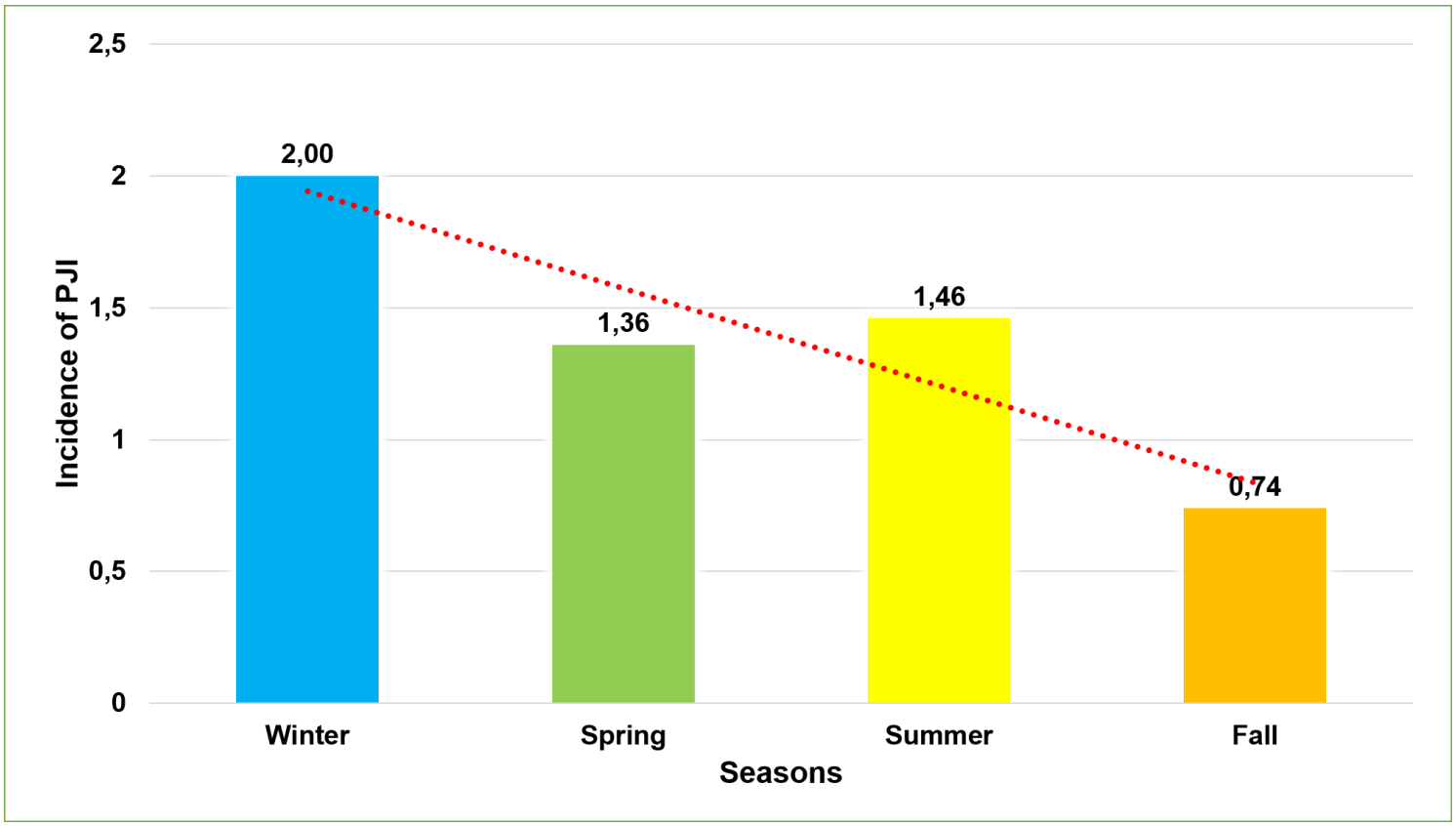


Figure 4

Seasonal variation in PJI incidence.

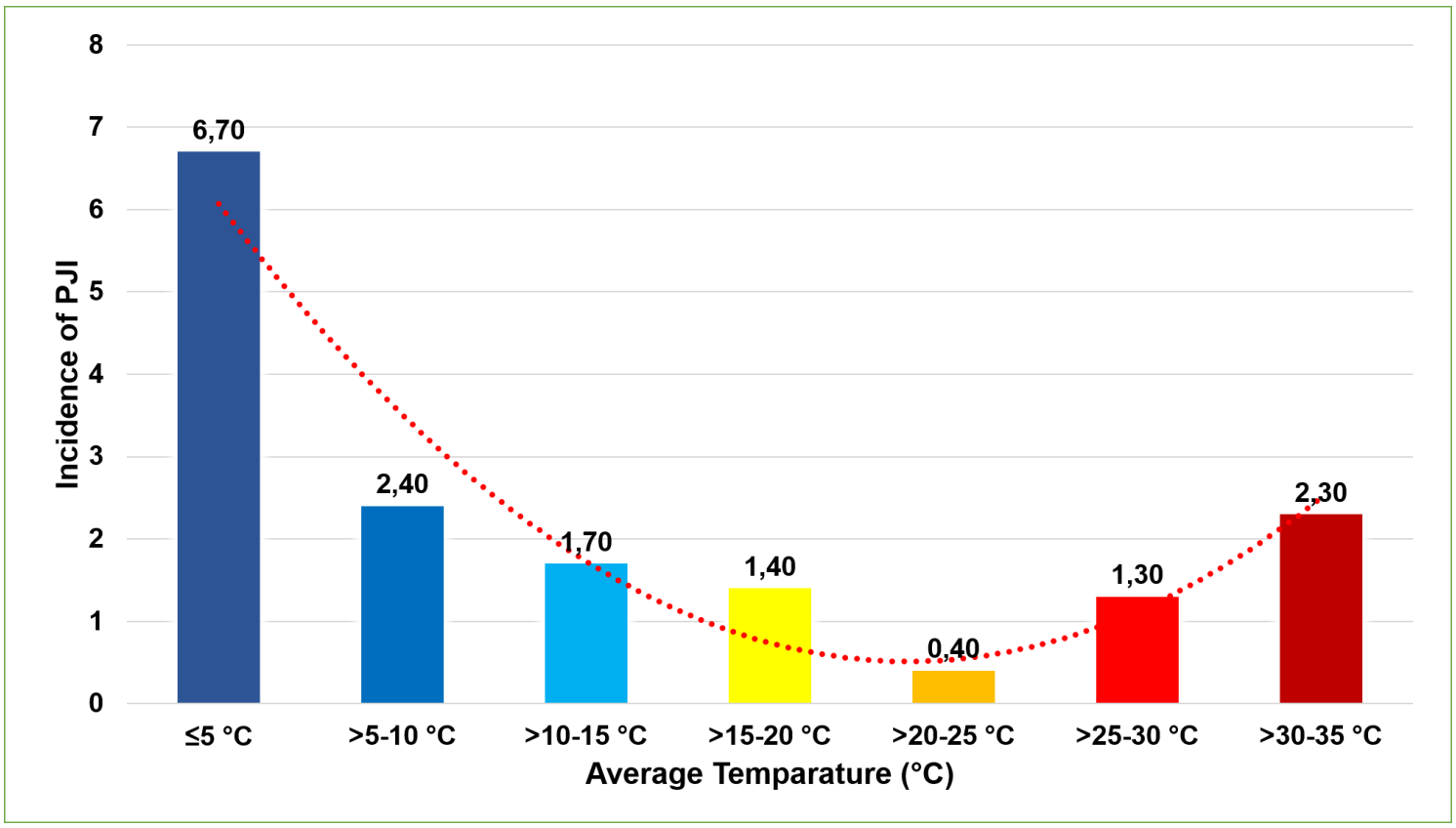


Figure 5

Incidence of PJI by temperature categories. The graph highlights that the highest PJI incidence occurs at temperatures ≤5°C, with lower infection rates observed in the 20-25°C temperature range, corresponding to optimal thermal comfort for humans.

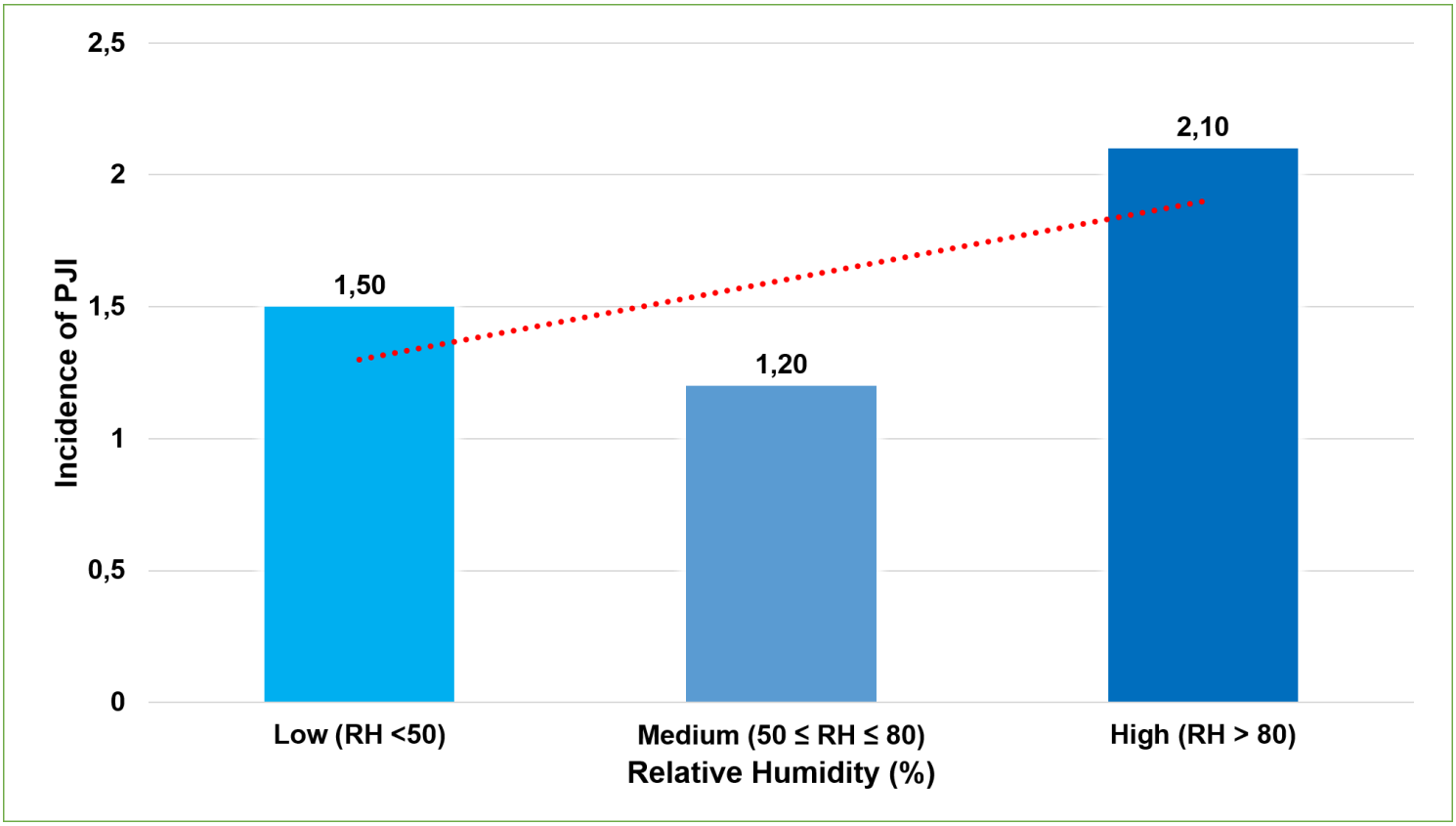


Figure 6

Incidence of PJI by relative humidity.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.docx
- Table2.docx
- Table3.docx
- Table4.docx
- Table5.docx