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Time series analysis of urethral obstruction in male cats in a veterinary teaching hospital in São paulo, Brazil

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Time series analysis can be used to understand and forecast patterns in sequential data. This study evaluated three statistical models—ARIMA, Holt-Winters, and linear regression—on the time series of urethral obstruction (UO) cases in male cats treated at the Veterinary Teaching Hospital – São Paulo State University, Botucatu, Brazil. Among the 5,230 cats evaluated between 2010 and 2020, the prevalence of UO in male cats was 7.4% (95% CI: 6.7–8.1%), and the incidence among cats showing lower urinary tract signs was 36.0% (95% CI: 33.19–38.93%). Most affected cats were neutered (60.94%), with a mean body weight of 4.24 ± 1.11 kg and higher body condition scores. ARIMA closely followed historical data but was ineffective for future forecasting, showing a flat projection from 2021 to 2024 (rate: 0.64) despite past fluctuations. The Holt-Winters model projected a rise in UO cases, from 0.70 (95% CI: 0.43–0.97) in 2021 to 1.09 (95% CI: 0.38–1.79) in 2024, but its wide confidence intervals indicated potential overestimation. Meanwhile, linear regression revealed a significant annual increase of 2.6% in UO cases ($p = 0.042$), explaining 38% of the variance and offering a more accurate long-term forecast, and then, was considered the most suitable model, capturing trends without overestimating future rates. These findings support improved surveillance, clinical protocols, preventive strategies, and hospital resource planning for managing UO in male cats in a teaching veterinary hospital scenario.

Keywords Auto regressive integrated moving average (ARIMA), *Felis catus*, Holt-winters, Incidence, Linear regression

In medical emergencies predominantly affecting male cats, urethral obstruction (UO) stands out as one of the most relevant conditions involving the urinary tract[1,2]. It is frequently associated with feline lower urinary tract disease (FLUTD), a clinical syndrome widely reported in veterinary practice[3]. Urine retention may rapidly lead to systemic deterioration and potentially death. These cases require medical stabilization, hospitalization for relief of obstruction, and intensive monitoring, with variable hospitalization times[3–6]. In this context, understanding the behavior of the disease over a series of timelines, as well as estimating future patterns, may be valuable.

Time series analysis is a valuable tool for modeling temporal patterns and forecasting future trends in both infectious and non-infectious diseases[7]. Despite its broad application in human epidemiology, its use in veterinary medicine – particularly for small animal diseases – remains limited. Common statistical models employed in time series analysis include autoregressive integrated moving average (ARIMA), Holt-Winters, and linear regression, each offering specific advantages depending on data structure[8–10]. In veterinary epidemiology, linear regression has been used to evaluate the risk of diseases[11]while ARIMA and Holt-Winters models have been applied to predict disease outbreaks[12] and assess public health impacts during epidemics[13].

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The UO in male cats can have various causes, including feline idiopathic cystitis (FIC), urethral plugs (p), urolithiasis (u), urinary tract infection (UTI), neoplasms (neo), and anatomical defects (ad)[3,14–16]. The prevalence of different etiologies of UO in male cats has been reported over time and varies according to the population studied. For instance, Kruger et al.[17] demonstrated that UO caused by urethral plugs occurs in approximately 21% of cats diagnosed with FLUTD. Gerber et al.[14] identified idiopathic FLUTD (53.3%), urolithiasis (28.8%), and urethral plugs (17.7%) as the main causes of UO in a population of 45 cats. Similarly, Dorsch et al.[15] observed that UO was significantly more frequent in cats with FIC (57.1%) than in those with UTI (28.5%). More recently, Lew-Kojrys et al.[16] also reported that UO was more common in cats with FIC (55.1%), urethral plugs (100%), and urolithiasis (56.0%), compared to those with UTI (13.3%) and neoplasms (25.0%), in a population of 229 cats with obstructive FLUTD.

Numerous male cats with UO are annually admitted to the Veterinary Teaching Hospital of the São Paulo State University (UNESP) in Botucatu, São Paulo. In recent years, an apparent increase in UO cases has been noted, raising concerns about potential seasonal patterns or long-term trends. However, there is currently a lack of data-driven methods to quantify such trends, forecast future cases, or inform hospital resource planning.

Therefore, the aim of this study was twofold: (1) to determine the prevalence and incidence of UO over an 11-year period; and (2) to evaluate which among three time series models—ARIMA, Holt-Winters, and linear regression—best captures the observed temporal patterns of UO in male cats. This approach seeks to address a relevant gap in veterinary epidemiological literature and to provide data-driven insights for clinical planning and disease prevention strategies.

Methods

Ethics statement

This study followed the recommendations of the Brazilian National Council for the Control of Animal Experimentation (CONCEA) and was approved by the Ethics Committee on the Use of Animals (CEUA) in Research at the School of Veterinary Medicine and Animal Science (FMVZ) at the São Paulo State University — UNESP (0235/2021). All procedures followed the guidelines and regulations of UNESP ethics council. Before any medical intervention and for inclusion in the study, a written informed consent was obtained from all cat owners. The research followed ARRIVE criteria.

Eligibility assessment and data collection

A retrospective review was conducted using 5,230 medical records of cats treated at the Veterinary Teaching Hospital of FMVZ–UNESP in Botucatu, São Paulo, Brazil, a region known for having a high number of cases of UO. Two independent reviewers manually screened records to identify male cats presenting clinical signs consistent with FLUTD, including ischuria, hematuria, stranguria, pollakiuria, periuria, or dysuria. From this initial cohort, only cases diagnosed with UO were selected, regardless of the underlying etiology.

Exclusion criteria included absence of LUT signs, female sex, diagnosis of non-obstructive FLUTD, comorbidities of infectious, parasitic, fungal, or traumatic nature, and duplicate records. A total of 386 male cats with UO met all inclusion criteria and were retained for final analysis.

Among the selected animals, data on sex, age, breed, body weight, reproductive status (neutered or intact), and clinical signs presented in the emergency room were noted.

Statistical analysis

Data distribution was analyzed using the Shapiro-Wilk test. Parametric analyses were performed on the variables body weight and number of UO cases. Comparison of body weight between castrated and intact animals was performed using the unpaired t-test. Data are shown as the mean ± standard deviation (SD). Significant differences were considered when $p < 0.05$. The nonparametric Mann-Whitney test was applied to compare the BCS values between castrated and intact animals; the results are shown as median (Q1–Q3). Significant differences were considered when $p < 0.05$. Comparison between the cause of UO, BCS, and body weight was also performed. Diet and breeds were considered for descriptive analysis.

The obstruction rate, calculated as the ratio between the number of UO cases per year and the number of cats per year, was analyzed using ARIMA (autoregressive integrated moving average) time series models. ARIMA models are effective for modeling stationary data; they capture temporal dependencies through autoregressive (AR), differencing (I), and moving average (MA) components. Model selection and parameter estimation (p, d, q) were guided by autocorrelation function (ACF) and partial autocorrelation function (PACF) plots. Likewise, the Akaike Information Criterion (AIC) was used to optimize the model, with parameters set to h = 24 h and a 95% confidence level. This modeling strategy allows for the identification of autocorrelated structures and seasonal fluctuations. The finalized ARIMA model was then used to project UO cases in cats for the years of 2021, 2022, 2023, and 2024. All analyses were conducted using the "stats," "tseries," and "forecast" packages in R (version 4.1.3).

The Holt-Winters exponential smoothing model was applied to capture trend and seasonality in the time series data. This model assigns greater weight to more recent observations while exponentially decreasing the influence of older values[9]. It decomposes the data into three components: a baseline value (representing the overall mean of the period), a trend, and seasonal components, which improves forecast accuracy, especially in cases of non-stationary time series. Based on these patterns, the model provides an exponential forecast for the trend in the next cycle. Likewise, projections for the period 2021–2024 were employed.

Finally, a simple linear regression model was developed with year as the dependent variable and case rate as the independent variable to determine the regression equation. A scatter plot with the fitted regression line was created for visualization. The regression model is represented as follows[18].

$$Yi = A + BXi + Ei$$

Yi represents the response variable, B is the slope coefficient indicating the average change in Y per one-unit increase in X, A is the intercept (the value of Y when X = 0 e Ei), and Ei denotes the error term for each predicted value. To further illustrate these analyses, boxplots and time series plots were generated. A 5% significance level was applied, and all analyses were conducted using R software (version 4.1.0; R Core Team, 2021).

Results
Study population data
In the survey of cases, 5,230 cats were seen between January 2010 to December 2020 at the Veterinary Teaching Hospital of the UNESP in Botucatu, São Paulo. Of the 5,230 records of cats found in the hospital database, 4,158 (79.5%) were excluded due to not presenting signs of the LUT. Furthermore, among the remaining cats, 295 (5.64%) were females and were subsequently excluded from the study. Among the remaining male cats, 198 (3.7%) were diagnosed with nonobstructive FLUTD. Out of the male cats with UO, 92 (1.75%) presented with other comorbidities, which included infectious, parasitic, fungal, or traumatic conditions (car accident, fight with other animals). Additionally, 101 (1.9%) cats with duplicate records were excluded from the analysis (Fig. 1).

Following the application of the exclusion criteria, 386 male cats (7.4%; 95% CI: 6.7–8.1%) were retained for analysis and diagnosed with UO (Fig. 2). The mean body weight of these cats with UO was 4.24 ± 1.11 kg, and the mean age was 98.40 ± 53.94 months. Of the cats with information on reproductive status, 60.94% were castrated (181/297) and 39.06% were intact (116/297).

In our study, castrated male cats exhibited a greater body weight (4.66 kg ± 1.13 kg) compared to intact male cats (3.77 kg ± 1.11 kg) ($p < 0.001$). Additionally, when considering reproductive status and BCS, castrated male cats had higher BCS compared to intact cats, 6 (5–7) vs. 5 (4–5.75) ($p < 0.0001$). In the population of cats with UO of our study, the distribution frequency according to the breed is presented in Fig. 3a. Notably, the most common type of diet provided by owners, primarily dry food, is depicted in Fig. 3b.

In investigating of the causes of UO among the 386 cats, an underlying cause was identified in 15.3% ($n = 59$) of cases. These underlying causes were found either in isolation or in combination within the same animal. FIC appears to be the most common cause of UO in the study population. Incomplete medical records prevented the determination of the underlying causes of UO in 327 cats (Fig. 3c).

LUT and systemic clinical signs, including depression, anorexia or hyporexia, polydipsia, hypothermia, and erection were evaluated (Supplementary Fig. S1). In our study, each cat ($n = 386$) presented at least two clinical signs upon emergency care. The frequency of clinical signs categorized by the cause of UO is presented in Table 1.

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Prevalence and incidence
The calculated mean annual prevalence of UO considering the total cat population ($n = 5{,}230$) was 7.4% (95% CI: 6.7–8.1%). Among the total cat population, 1,072 showed LUT signs. For this subset of cats ($n = 1{,}072$), the mean annual incidence of UO was 36.0% (95% CI: 33.19–38.93%) (Fig. 4, Supplementary Table S1).

Time series analysis
To analyze the projection of cases over the years, the autoregressive integrated moving average (ARIMA), Holt-Winters, and linear regression methods were applied.

For the ARIMA method, the annual case rate as a time series, along with the autocorrelation function (ACF) and partial autocorrelation (PACF) plots are presented in Supplementary Fig. S2. The model aligns well with the data, as the observations fall within the confidence limits in both autocorrelation and partial autocorrelation analyses.

In the projection analysis for the years of 2021, 2022, 2023, and 2024, it was predicted a rate of 0.64 of UO in male cats, maintaining the same pattern with no oscillations (Fig. 5). However, based on the fluctuations observed from 2010 to 2020 it is not possible to confirm that the consistency rate will remain stable in the projected years, making this model unsuitable for predicting future case rates.

Conversely, the predictive Holt-Winters model showed an increase in the rate of UO in male cats over the projected years (2021 to 2024) (Fig. 6). The predicted rate for 2021 was 0.70 (95% CI: 0.43–0.97). In 2022, the predicted rate increased to 0.83 (95% CI: 0.46–1.20), while for the year of 2023, the rate was 0.96 (95% CI: 0.44–1.48). Finally, for 2024, a predicted rate of 1.09 (95% CI: 0.38–1.79) was encountered. These results reflect a rising trend in case rate over the years, with broader confidence intervals for more distant projections.

In the linear regression model, the results indicated a mean annual increase of 0.026 (2,6%) in the rate of cases of UO ($p = 0.042$) (Table 2; Fig. 7). The adjusted coefficient of determination suggested that 38% of the variation in the cases rate is explained by the model. Besides the variation in the rate of UO over the years, a linear behavior could be observed with a tendency of increase of 2.6% per year.

Discussion
This study is the first to present epidemiological data on the incidence and prevalence of UO in male cats and to apply time series modeling to investigate long-term trends in feline UO in a veterinary teaching hospital setting. Over an 11-year period, our study evaluated three statistical models—ARIMA, Holt-Winters, and linear regression—to forecast case rates and describe epidemiological patterns.

In our study, the mean annual prevalence of 7.4% significantly exceeded previous reports[19,20] and closely aligned with findings from Lekcharoensuk et al.[1]. These discrepancies in prevalence across studies may be attributed to population differences, caseload characteristics of referral centers, or regional environmental

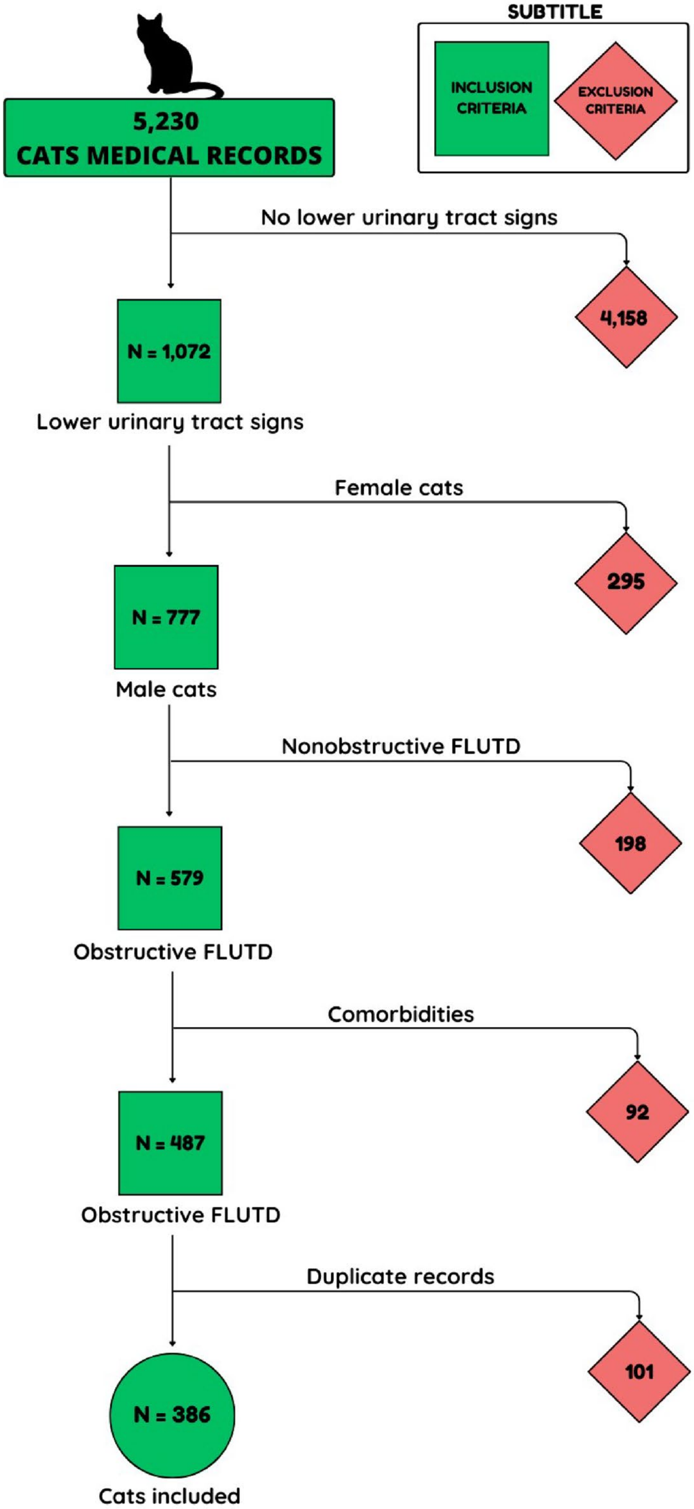

Fig. 1. Flowchart illustrating the decision-making process (inclusion and exclusion criteria) for obtaining the study population ($n = 386$).

influences. In contrast, the incidence of UO in North American veterinary hospitals has ranged from 2–13%,[21]differing from our reported mean annual incidence. This variation is also evident when compared to Jukes et al.[21], who found higher incidence rates. Notably, our study focused on male cats with UO, whereas previous reports included both sexes.

Regarding the demographic characteristics of affected male cats, our findings align with previous reports, with a predominance of middle-aged, neutered male cats exhibiting higher body weight and BCS. These factors have

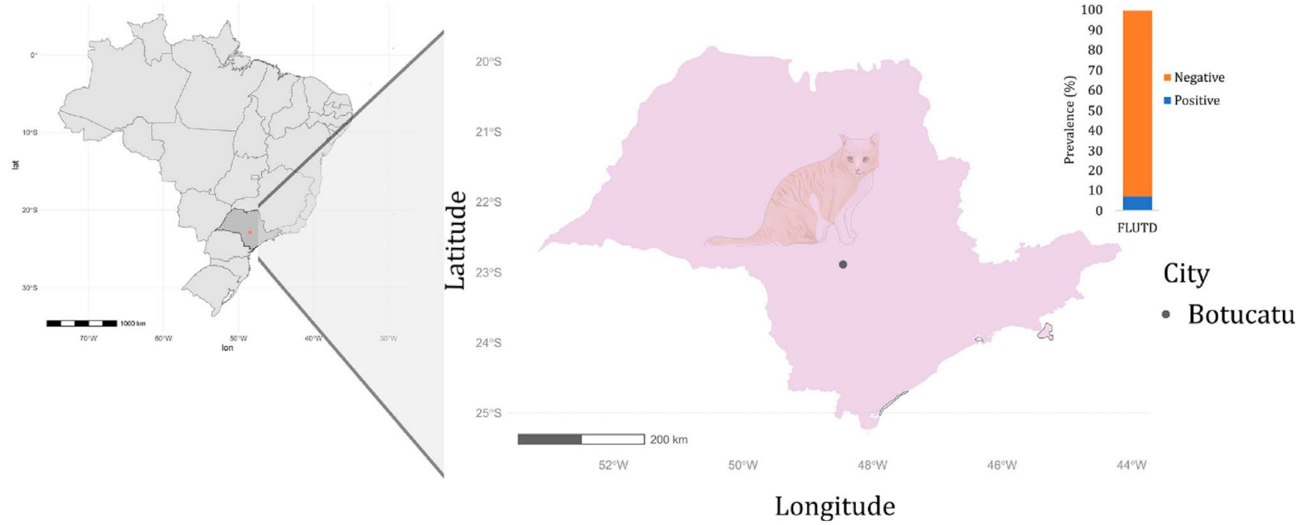

Fig. 2. Territorial representation of Botucatu (latitude 22° 53'09" south and longitude 48° 26'42" west") in São Paulo, Brazil, and mean annual prevalence of the period considered in the study (January 2010 to December 2020). The figure was generated using the rnaturalearth package (https://github.com/ropensci/rnaturalearth) and ggplot (https://ggplot2.tidyverse.org/), on the R platform. This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 3.0 International License.

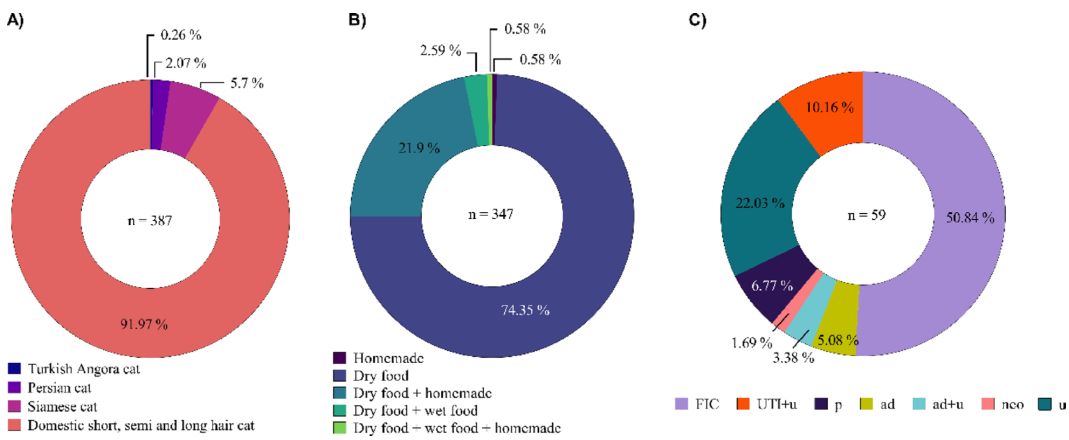

Fig. 3. Percentual representation of male cat breeds, diet, and cause of obstruction. (**a**) Percent ratio of male feline breeds. (**b**) Main diets provided by owners to male cats diagnosed with urethral obstruction (UO). (**c**) Main causes of UO in 59 male cats with a conclusive diagnosis. Feline idiopathic cystitis (FIC); urinary tract infection (UTI); urolithiasis (u); plugs (p); anatomical defect (ad); neoplasia (neo).

been consistently associated with an increased risk of UO[16,22,23] possibly due to anatomical and physiological predispositions. Similarly to previous studies[16,24,25], the presence of multiple underlying cause for UO was also noted in our study, with FIC being the predominant etiology. In this context, the integration of behavioral, environmental, and systemic health data into clinical surveillance could enable the development of etiology-specific forecasting models. Such multidimensional approaches may yield improved predictions of recurrence risk and help identify subpopulations of cats more susceptible to UO under specific stress or immunological conditions[3,26,27].

The clinical signs most commonly observed in our study, including dysuria, stranguria, and pain-related behaviors, further support the established pathophysiology of FLUTD, in which stress-induced neurogenic inflammation plays a central role[26,28,29]. Although LUT signs are commonly observed in feline UO, additional clinical manifestations associated with the duration of urinary retention (ischuria) may also be present[2,5,19]. In our study, clinical signs such as anorexia, hyporexia, depression, and hypothermia were identified.

In the application of time series modeling to investigate long-term trends in feline UO, the three statistical models—ARIMA, Holt-Winters, and linear regression—revealed different trends towards case rates. While the ARIMA model aligned with historical data, it predicted a flat trend for future years. However, given the fluctuations in case rates observed from 2010 to 2020 it is not possible to confirm that the consistency rate will

	Frequency Distribution ($n=59^{*\dagger}$)						
Clinical sign	FIC (n = 30)	Urolithiasis (n = 13)	UTI + urolithiasis (n = 6)	Urolithiasis + anatomical defects (n = 2)	Plugs (n = 4)	Anatomical defects (n = 3)	Neoplasia (n = 1)
Dysuria	93.3%	84.6%	66.6%	100%	100%	100%	100%
Stranguria	83.3%	84.6%	83.3%	100%	100%	100%	100%
Anorexia/hyporexia	63.6%	69.2%	66.6%	100%	100%	33.3%	100%
Hypothermia	53.3%	46.1%	16.6%	50%	50%	66.7%	0%
Depression	56.6%	38.5%	16.6%	50%	75%	33.3%	100%
Pollakiuria	53.3%	69.2%	66.6%	100%	75%	66.7%	100%
Hematuria	20%	38.5%	33.3%	50%	75%	33.3%	0%
Grooming (penis)	20%	23.1%	0%	50%	50%	33.3%	0%
Agitation	13.3%	15.4%	0%	50%	0%	0%	0%
Penile erection	13.3%	15.4%	0%	50%	0%	33.3%	0%

Table 1. Frequency distribution of lower urinary tract (LUT) and systemic clinical signs in male cats with urethral obstruction (UO) according to the underlying cause of obstruction: feline idiopathic cystitis (FIC), urinary tract infection (UTI), urolithiasis, plugs, anatomical defects, and neoplasia. The data are presented for 59 cats with the cause of UO identified from January 2010 to December 2020 after a complete investigation. Three cats with urethral obstruction had more than one diagnosis simultaneously, therefore, data on clinical signs were not presented considering the possibility of clinical signs overlapping between different causes of obstruction. † Incomplete medical records prevented the precise determination of the underlying cause of UO in 327 male cats.

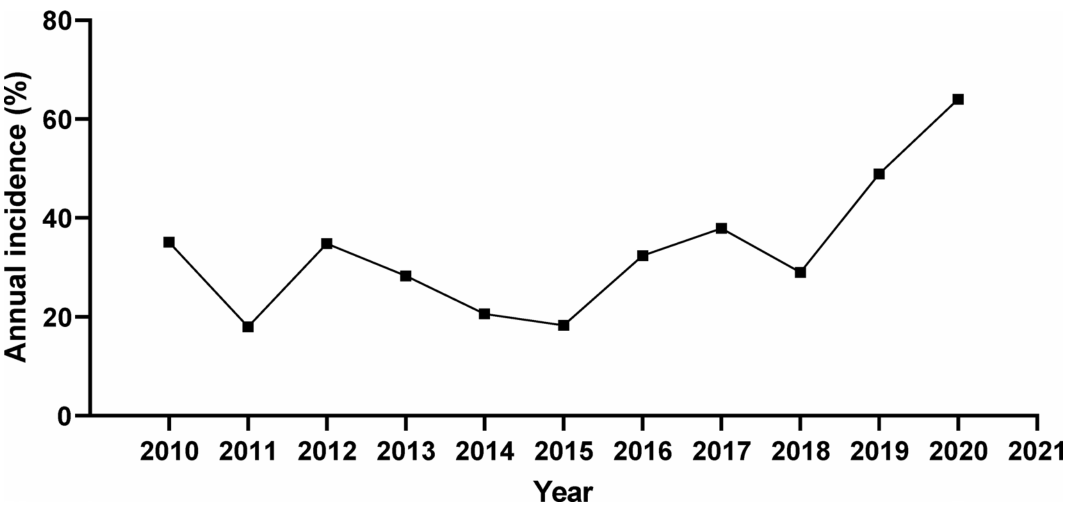

Fig. 4. Annual incidence for cases of urethral obstruction (UO) in male cats at the Veterinary Teaching Hospital in the São Paulo State University, Botucatu, São Paulo.

remain stable in the projected years, making this model unsuitable for predicting future patterns. Meanwhile, the Holt-Winters model showed a progressive increase in UO case rates over the year with broader confidence intervals for more distant projections. Although the model has applicability in our data setting, it may overestimate future projection trends. Conversely, the linear regression model identified a statistically significant annual increase of 2.6% in UO case rates. In our study, both Holt-Winters and linear regression models, demonstrated complementary results, highlighting a consistent upward trend in the case rates for UO, with linear regression fitting as the most reliable model to reflect more distant projections without overestimating UO case rates.

The increasing trend identified through these models underscores the growing clinical relevance of UO in feline practice. This trend may reflect both a genuine increase in incidence and improved detection or reporting practices over time. Importantly, this is the first study to quantify UO trends using predictive models, offering a valuable foundation for future surveillance and strategic hospital resource allocation.

A notable observation in our data was the increase in UO case rates during 2019 and 2020, which coincided with the onset of the COVID-19 pandemic. A recent study reported a similar rise in UO incidence during this period, suggesting that environmental changes – such as increased owner presence at home – may have

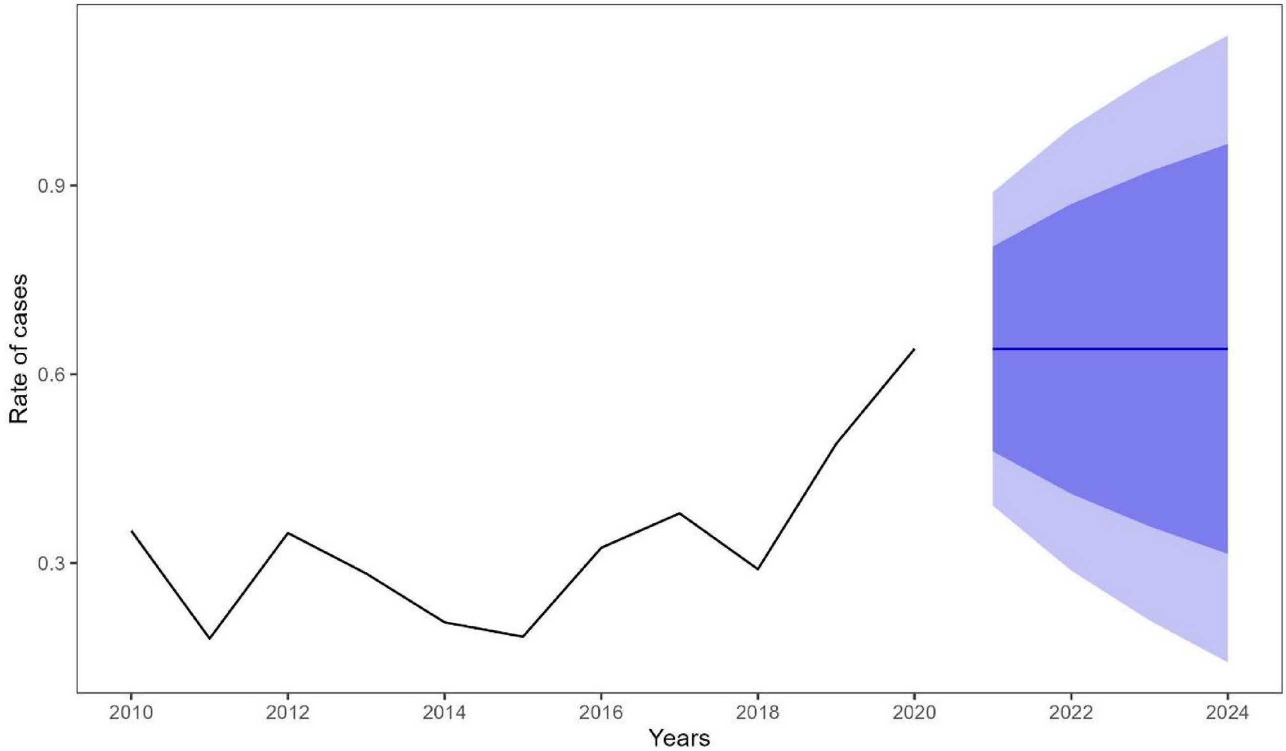

Fig. 5. Case rate prediction according to ARIMA (0,1,0).

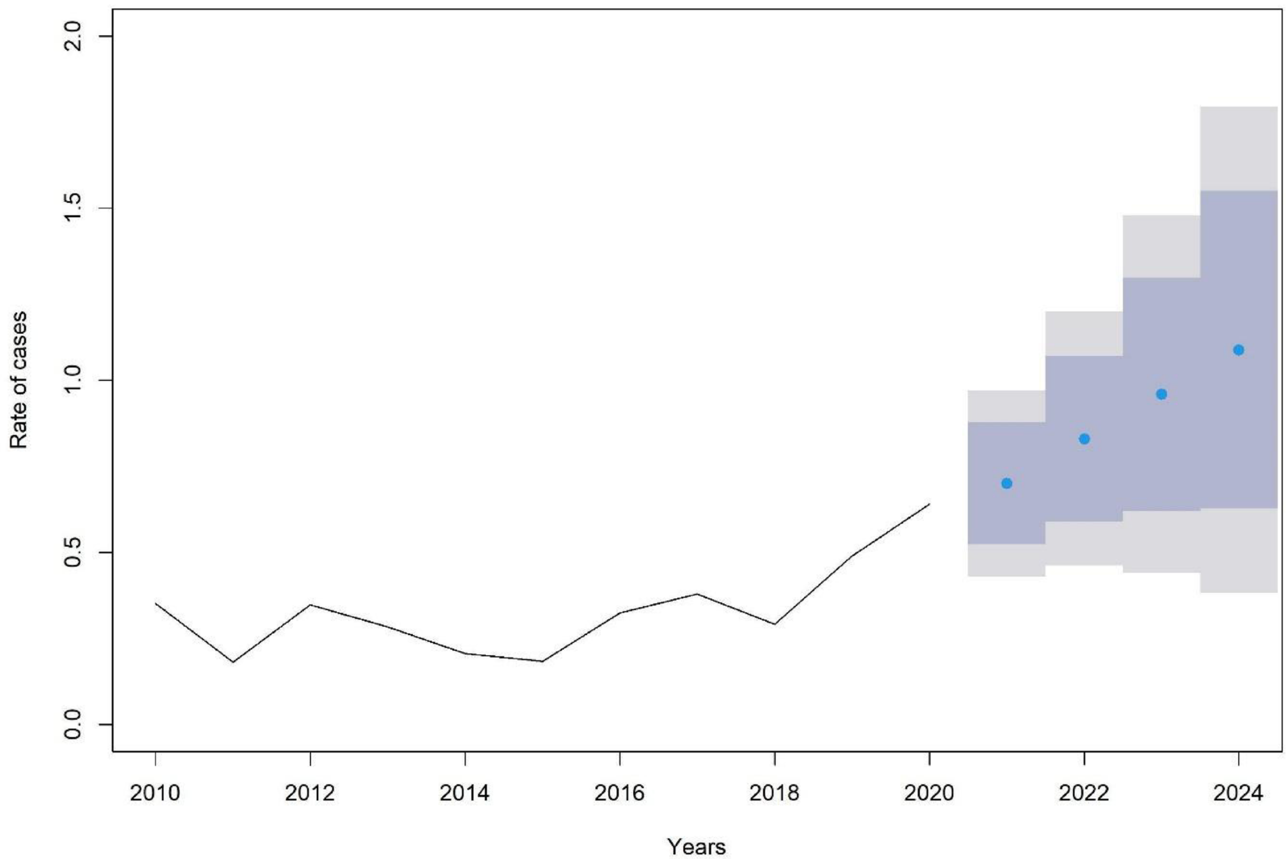

Fig. 6. Case rate prediction according to the Holt-Winters model.

Line equation	R^2	*p*-value	*p*-value test for normality of residuals*
y = 0.026x − 51.36	0.38	**0.042**	0.798

Table 2. Results of linear regression with the year as the dependent variable and the case rate as the independent variable. *Shapiro-Wilk test

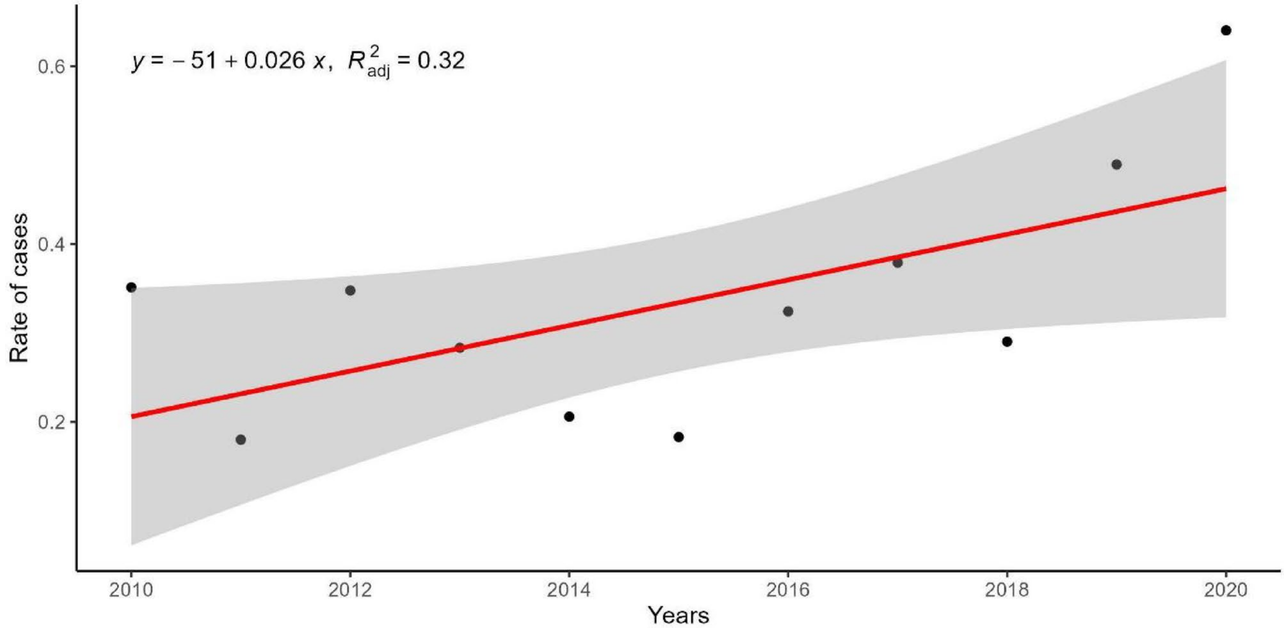

Fig. 7. Scatterplot and linear regression for case rate of UO over time.

heightened stress levels in cats and contributed to clinical expression of FLUTD[30]. In our setting, increased owner attentiveness may have facilitated earlier detection of clinical signs related to LUT. It is noteworthy that disruptions to feline routines and enriched environments could have exacerbated stress-related FLUTD. These findings support previous evidence that stress modulation plays a central role in UO pathogenesis[16,24,26]and emphasize the importance of incorporating environmental and behavioral variables into preventive strategies.

The upward trend in UO rates projected by the Holt-Winters and linear regression models may reflect not only long-term behavioral and environmental influences but also a potential persistence of the elevated incidence observed during the COVID-19 pandemic. While an increase in UO incidence during this period has been reported[30]our projections suggested that these changes may not have been transient. In contrast, Jackson et al.[31] found no significant difference between pre- and intra-pandemic UO rates. However, more recent findings by Dahmani and Zenia[32]covering 2023 and 2024—a period encompassed by our projections—also revealed higher UO rates compared to earlier studies[1,33,34]reinforcing the notion of a sustained increase in case frequency.

Moreover, the increase in UO during the COVID-19 pandemic demonstrated by time series analysis may be associated with changes in the diet and lifestyle of cats. The increase in food consumption combined with reduced physical activity leads to the development of obesity, a factor that predisposes to UO[35]. Thus, given the exposed, integrating epidemiological surveillance with contextual interpretation of societal events—such as pandemics—can improve clinical readiness and contribute to more effective allocation of resources in veterinary settings.

Although the primary focus of our study was the identification of the presence of UO, incomplete medical records prevented our ability to properly determine the UO etiology in a substantial number of animals due to incomplete laboratory and imaging test results. Thus, comprehensive documentation, diagnostic workups, and standardized protocols are essential to improve the accuracy of future retrospective analyses. Further investigations could benefit from integrating machine learning approaches with time series modeling to enhance predictive accuracy and improve identification of high-risk patients.

In conclusion, our study identified a high prevalence of UO cases in male cats, with a clear increasing incidence over recent years. Among the models tested, the Holt-Winters exponential smoothing model demonstrated to be complementary with the linear regression model. However, given the overestimation provided by the Holt-Winters model for more distant projections, linear regression showed to be the most suitable for predicting future case rates in our veterinary hospital setting for UO in male cats. These findings offer a valuable insight into future caseload expectations and underscore the importance of long-term monitoring of UO incidence and the integration of predictive analytics in veterinary epidemiology. The persistence of elevated case numbers beyond the pandemic period suggests that lifestyle and environmental factors may have a lasting influence on

UO risk, highlighting the need for targeted preventive strategies in clinical practice. Nevertheless, it enables the development and implementation of standardized clinical protocols and targeted staff training to appropriately manage the anticipated increase in admissions of male cats with UO in the coming years.

Data availability

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

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