ORIGINAL ARTICLE

The Influence of Meteorological Variables on the Occurrence of Deep Venous Thrombosis

L'influence des variables météorologiques sur la survenue de la thrombose veineuse profonde

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Abstract

Background: Deep venous thrombosis (DVT) risk factors are well-established, yet meteorological influences remain debated, especially in North Africa.
Aim: We assessed associations between meteorological factors, seasonal patterns, and DVT incidence in central Tunisia.
Methods: This monocentric cross-sectional study included 211 patients with 217 ultrasound-confirmed DVT episodes (2009–2021) residing in Sousse or Kairouan. Meteorological data were obtained from national sources. Multivariate analysis adjusted for residence and the COVID-19 period (2020–2021).
Results: Idiopathic DVT accounted for 53.9% of cases, peaking in winter (p=0.010), while cancer-associated DVT peaked in summer (p=0.017). No significant differences emerged between Sousse and Kairouan residents. Months with DVT exhibited higher cloud cover (19.2% vs. 16.89%, p=0.032) and lower atmospheric pressure (1018.36 vs. 1020.13 hPa, p=0.042). Multivariate analysis confirmed increased cloud cover (aOR=1.04, p=0.046) and lower pressure (aOR=0.88, p=0.047) as independent risk factors. COVID-19 period incidence was higher (IRR=1.46, p=0.032) but did not alter meteorological associations. Summer 2021 heatwave analysis confirmed result stability.
Conclusion: Lower atmospheric pressure and greater cloud cover independently increase DVT risk in central Tunisia. Seasonal patterns vary by etiology. Despite pandemic-related incidence increases, meteorological associations remained robust, suggesting weather modulates thrombotic risk.

Key words: deep venous thrombosis, meteorology, venous thromboembolic disease, climate, environment, Tunisia

Résumé

Contexte: Les facteurs de risque de thrombose veineuse profonde (TVP) sont établis, mais l'influence météorologique reste débattue, surtout en Afrique du Nord.
Objectif: Évaluer l'association entre facteurs météorologiques, variations saisonnières et incidence de la TVP en Tunisie centrale.
Méthodes: Étude transversale monocentrique incluant 211 patients avec 217 épisodes de TVP confirmés par échographie (2009–2021), résidant à Sousse ou Kairouan. Les données météorologiques provenaient de sources nationales. L'analyse multivariée a été ajustée sur la résidence et la période COVID-19 (2020–2021).
Résultats: La TVP idiopathique représentait 53,9 % des cas, avec un pic hivernal (p=0,010), tandis que la TVP liée au cancer culminait en été (p=0,017). Aucune différence significative n'est apparue entre les résidents de Sousse et Kairouan. Les mois avec TVP présentaient une couverture nuageuse plus élevée (19,2 % vs 16,89 %, p=0,032) et une pression atmosphérique plus basse (1018,36 vs 1020,13 hPa, p=0,042). L'analyse multivariée a confirmé qu'une couverture nuageuse accrue (ORa=1,04, p=0,046) et une pression plus basse (ORa=0,88, p=0,047) étaient des facteurs de risque indépendants. L'incidence était plus élevée pendant la COVID-19 (IRR=1,46, p=0,032) sans altérer les associations météorologiques. La canicule de l'été 2021 n'a pas modifié la stabilité des résultats.
Conclusion: Une pression atmosphérique basse et une forte couverture nuageuse augmentent indépendamment le risque de TVP en Tunisie centrale. Les schémas saisonniers varient selon l'étiologie. Malgré l'augmentation liée à la pandémie, les associations météorologiques restent robustes, suggérant une modulation du risque thrombotique par le climat.

Mots-clés: thrombose veineuse profonde, météorologie, maladie thromboembolique veineuse, climat, environnement, Tunisie

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Introduction

Venous thromboembolic disease (VTE) is a common pathology with an annual incidence exceeding 1 per 1,000 inhabitants in Europe and North America, where over 200,000 new cases are recorded each year [1]. It encompasses deep vein thrombosis (DVT) of the lower limbs, pulmonary embolism (PE), and superficial vein thrombosis. VTE is a serious condition with a mortality rate estimated at 4.55% patient-years, primarily linked to PE [2]. Pathophysiologically, vascular injury, hypercoagulability, and venous stasis—the Virchow triad—play a crucial role in its onset [3]. VTE is multifactorial, resulting from a complex interplay of clinical and biological risk factors [2,4].

Although VTE risk factors are well-identified, the precise triggers for these events often remain unclear. Meteorological variations and the resulting seasonal changes are closely linked to human health. For instance, influenza epidemics peak in winter in both the Northern and Southern Hemispheres [6]. Seasonal changes can also influence dietary intake [7] and physical activity levels in both children [8,9] and adults [10], potentially leading to seasonal variations in weight and cholesterol levels [11,12]. Adverse weather events can act as barriers to physical activity, thereby influencing certain diseases [13].

Several observational studies have investigated the relationship between meteorological data (atmospheric pressure, wind speed, mean temperature, humidity, etc.), seasonal variations, and VTE incidence [14–17]. Some report a higher number of DVT cases associated with increased humidity and wind speed, decreased atmospheric pressure, and during winter. However, other studies find no significant link [18–20]. To date, no studies have specifically examined the influence of seasonal and climatic variations on DVT occurrence in North Africa, a region characterized by distinct semi-arid to arid climates and limited epidemiological data on thrombotic diseases. Therefore, the primary objective of this work was to investigate an association between meteorological variations and the incidence of deep vein thromboses in central Tunisia. Secondary objectives included: (1) comparing meteorological data of months with and without recorded DVT cases; (2) analyzing seasonal patterns according to DVT etiology; (3) assessing potential differences between residents of the coastal city of Sousse and the inland city of Kairouan; and (4) evaluating the impact of the COVID-19 pandemic period and extreme climatic events (summer 2021 heatwave) on DVT incidence.

Methods

This was a monocentric, analytical, cross-sectional study conducted at the Internal Medicine Department of Farhat Hached University Hospital in Sousse, Tunisia. The study population consisted of all patients hospitalized for DVT over a 13-year period, from January 1, 2009, to December 31, 2021.

Patients eligible for inclusion were adults (aged ≥ 18 years) hospitalized and followed in the Internal Medicine Department with deep vein thrombosis (DVT) confirmed by lower limb venous Doppler ultrasound, whether or not associated with superficial thrombophlebitis, and residing in the Sousse or Kairouan governorates. Exclusion criteria comprised age under 18 years, DVT at unusual sites (i.e., thrombosis located outside the lower limbs), outpatient management of lower limb DVT, and residence outside the Sousse or Kairouan governorates.

Data were collected using a pre-established form including demographic, clinical, paraclinical, and therapeutic characteristics. For each patient, the season and the exact date of positive diagnosis were recorded. Meteorological data (mean, maximum, and minimum temperature, atmospheric pressure, dew point, wind speed and temperature, humidity, precipitation, cloud cover) recorded daily in Sousse and Kairouan during the study period were obtained from the National Institute of Meteorology of Tunisia and cross-verified with World Weather Online (https://www.historique-meteo.net), sourced from the Moureddine station (Sousse) and the Chebika station (Kairouan) [21]. Acknowledging the climatic differences between the coastal city of Sousse (Mediterranean semi-arid climate) and the inland city of Kairouan (continental arid/semi-arid climate) [22], a pre-specified subgroup analysis was performed to compare DVT incidence, clinical characteristics, and meteorological associations between residents of both governorates.

Seasonal analysis used meteorological seasons [23]: spring (March 1 – May 31), summer (June 1 – August 31), autumn (September 1 – November 30), and winter (December 1 – February 28/29). The COVID-19 pandemic period was defined as March 2020 through December 2021, and was included as a binary adjustment variable in multivariate models. A sensitivity analysis was conducted excluding the extreme heatwave period of summer 2021 (notably August 2021, when temperatures reached 50.3°C in Kairouan) to assess result robustness.

Statistical analysis was performed using SPSS 21.0 software and reviewed by an independent biostatistician. The normality of quantitative variables was verified using the Kolmogorov-Smirnov test. Normally distributed variables were expressed as mean ± standard deviation (SD); non-normally distributed variables were expressed as median with interquartile range (IQR). Qualitative variables were expressed as counts and percentages. Comparisons of qualitative variables were made using the Chi-square test or Fisher's exact test when theoretical counts were insufficient ($n < 5$). Comparisons of quantitative variables (means) were performed using Student's t-test or the non-parametric Mann-Whitney U test when conditions of validity were not met. The relationship between two quantitative variables was assessed using Pearson's correlation coefficient (for large samples) or Spearman's rank correlation coefficient (for small samples).

For multivariate analysis, a multiple binary logistic

regression was performed, with the absence or presence of a DVT case as the dependent variable. Variables significant at $p < 0.20$ in univariate analysis were introduced into the model. The final model was adjusted for residence governorate (Sousse vs. Kairouan) and the COVID-19 pandemic period. The strength of association was estimated using Odds Ratios (OR) and their 95% Confidence Intervals (CI). For all statistical tests, the significance threshold p was set at 0.05. Incidence rate ratios (IRR) with 95% CI were calculated to compare monthly DVT incidence during the COVID-19 period versus the pre-pandemic period.

This study was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was obtained from the Institutional Ethics Committee, and all data were processed anonymously to ensure patient confidentiality.
Artificial intelligence tools were used to assist in the writing process, specifically for language refinement, grammatical correction, and improvement of phrasing. The authors retain full responsibility for the content, accuracy, and integrity of the final manuscript.

Results

During the study period, 217 cases of lower limb DVT were recorded in 211 patients, including 6 patients hospitalized for recurrence.
There were 115 women (54%) and 96 men (46%) with a sex ratio F/H = 1.19. The mean age of the patients was 56.9 ± 19.06 years (19–90 years) and 38.9% of the patients were older than 65 years. The majority of patients (90.5%) lived in the governorate of Sousse. A family history of DVT was found in 4 patients (1.8%). One hundred and twenty patients (56.9%) had one or more comorbidities. The main comorbidities were hypertension (23.7%), diabetes (18%), DVT (11.4%), active cancer (10.4%), Behçet disease (1.4%), and antiphospholipid antibody syndrome (1.9%) (Table I).
A factor favoring the occurrence of DVT was found in 128 cases (57.7%). DVT was located in the left lower limb in 61.7% of cases, in the right lower limb in 33.2% of cases and was bilateral in 11 cases (5%). DVT was proximal in 190 cases (87.6%) and distal in 27 cases (12.4%). The etiological investigation concluded that DVT was unprovoked in 117 cases (53.9%), cancer in 40 cases (18.4%), hyperhomocysteinemia in 38 cases (17.5%), Behçet disease in 12 cases (5.5%), antiphospholipid syndrome in 8 cases (3.7%) and constitutional thrombophilia in 2 cases (1%) (Table 1).

Seasonal distribution showed 59 cases (27.2%) in spring, 58 cases (26.7%) in summer, 58 cases (26.7%) in winter, and 42 cases (19.4%) in autumn. Univariate analysis revealed statistically significant seasonal variations for specific subgroups. The occurrence of idiopathic DVT was significantly higher in winter (p = 0.010), while DVT associated with cancer was significantly more frequent in summer (p = 0.017). A significant seasonal variation was also found for DVT occurrence in men, which peaked in summer (p = 0.020).

Table 1. Distribution of the population by socio-demographic and clinical data

socio-demographic and clinical characteristics N (211)	n(%)
Gender	
Man	96(46)
Woman	115(54)
Age (years)	
< 25	9(4.3)
25- 45	48(22.7)
45- 65	72(34.1)
> 65	82(38.9)
Origin	
Sousse	191(90.5)
Kairouan	20(9.5)
History	
Arterial hypertension	50(23.7)
Diabetes	38(18)
DVT	24(11.4)
Cancer	22(10.4)
Behçet's disease	3(1.4)
APLA	4(1.9)
Others	20(9.5)
DVT location	
proximal	190(87.6)
distal	44(12.4)
DVT side	
Left lower limb	134(61.7)
Right lower limb	72(33.2)
Bilateral	11(5)
Etiology	
Idiopathic	117(53.9)
cancer	40(18.4)
Hyperhomocysteinemia	38(17.5)
Behçcet's disease	12(5.5)
APS	8(3.7)
Constutional thrombophilia	2(1)

Subgroup analysis: Sousse versus Kairouan residents

Of the 217 DVT episodes, 197 (90.8%) occurred in residents of Sousse and 20 (9.2%) in residents of Kairouan. Comparison between the two groups revealed no statistically significant differences in demographic characteristics, clinical features, DVT localization, etiological distribution, or seasonal patterns (all $p > 0.05$). Although expected climatic differences were confirmed—Sousse residents experienced significantly higher mean wind speed (23.38 vs. 20.30 km/h, $p<0.001$), humidity (68.95% vs. 65.80%, p=0.033), and dew point (14.16 vs. 11.30°C, p=0.006)—the key meteorological parameters associated with DVT in the main analysis (atmospheric pressure and cloud cover) did not differ significantly between the two locations. Consequently, residence governorate was included as an adjustment variable in multivariate models, and no interaction effect was detected.

Impact of the COVID-19 pandemic period

During the defined COVID-19 period (March 2020–December 2021), 47 DVT cases were recorded, compared to 175 cases in the pre-pandemic period (January 2009–February 2020). Monthly DVT incidence was significantly higher during the pandemic period (1.91 vs. 1.31 cases/month; Incidence Rate Ratio = 1.46, 95% CI [1.04–2.05], p=0.032), representing a 46% relative increase. However, adjustment for the pandemic period in the multivariate model did not materially alter the associations between meteorological variables and DVT risk, suggesting that the observed weather-DVT relationships were independent of pandemic-related confounders.

Sensitivity analysis: Summer 2021 extreme heatwave

During the extreme heatwave of summer 2021 (notably August 2021, with record temperatures of 50.3°C in Kairouan), 7 DVT cases were recorded, compared to a mean of 4.17 cases (range: 1–8) in other summer periods. This difference was not statistically significant (p=0.13). Excluding this period from the main analysis did not change the direction or significance of the meteorological associations, confirming the robustness of our findings.

Meteorological analysis of the 118 months with at least one DVT case showed that the frequency of DVT peaked at a mean temperature of 15°C, a wind speed of 24 km/h, and a daily precipitation of 1 mm (all $p < 0.001$). When comparing the average meteorological parameters of months with DVT (n = 118) versus months without DVT (n = 38), two variables showed statistically significant differences: cloud cover was higher (19.2% vs. 16.89%, p=0.032) and atmospheric pressure was lower (1018.36 vs. 1020.13 hPa, p=0.042) in months with DVT.

Multivariate logistic regression analysis, adjusting for potential confounders (including residence governorate and the COVID-19 pandemic period), confirmed that an increase in cloud cover was independently associated with a higher risk of DVT occurrence (Adjusted OR = 1.04, 95% CI [1.001–1.092], p = 0.046), while an increase in atmospheric pressure was independently associated with a lower risk (Adjusted OR = 0.88, 95% CI [0.786–0.997], p = 0.047) (Table 2).

Table 2. Comparison of average weather parameters for months without Deep Vein Thrombosis versus months with Venous Thrombosis deep vein thrombosis

weather parameters	Months without DVT (Mean±SD)	Months with DVT (Mean±SD)	p
Average temperature (°C)	21.11±5.976	21.26±5.964	0,89
Max temperature (°C)	23.71±6.022	23.76±6.282	0.93
Min temperature (°C)	18.53±6.003	18.45±6.057	0.93
Wind speed (km/h)	23.16±2.766	23.10±3.117	0.69
Wind temperature (°C)	17.71±6,900	17.69±6.813	0.84
Average daily precipitation	1.61±1.028	1.69±1.105	0.40
Total precipitation per month	31.71±33.279	33.53±35.181	0.36
Humidity (%)	68.92±5.716	68.66±6.314	0.77
Cloud cover (%)	16.89±7.093	19.20±9.666	0.03
Atmospheric pressure (hPA)	1020.13±3.670	1018.36±3.003	0.04

Discussion

This study, conducted over a 13-year period in central Tunisia, provides evidence for an association between meteorological conditions and the occurrence of DVT. The primary findings are that lower atmospheric pressure and higher cloud cover are independent predictors of increased DVT incidence. Furthermore, the study showed that seasonal patterns are not uniform and vary significantly based on the etiology of the thrombosis, with idiopathic cases peaking in winter and cancer-associated cases peaking in summer. These findings add valuable epidemiological data to the scarce literature regarding VTE in North Africa.

The finding that lower atmospheric pressure is associated with a higher risk of DVT aligns with several previous studies. Brown et al. suggested an inverse correlation, reporting that a 10-millibar decrease in atmospheric pressure nine days prior to diagnosis was linked to a 2.1% increase in DVT incidence [31]. Similarly, Esquenet et al. found an association between DVT and low atmospheric pressure [32]. An experimental study on healthy volunteers exposed to hypobaric conditions showed a transient increase in markers of activated coagulation, providing a potential physiological mechanism for this association [34].

The association with increased cloud cover is a novel finding of this study. While cloud cover itself may not be a direct causal factor, it is a robust indicator of specific weather systems, often associated with low-pressure fronts, higher humidity, and precipitation. The multivariate model suggests that cloud cover may be a stronger or more stable predictor than precipitation or humidity alone in this population.

The seasonal variation observed, particularly the peak of idiopathic DVT in winter, is consistent with the majority of the literature [14,24–26,30]. This is often attributed to cold-induced vasoconstriction, reduced physical activity during colder months [27], and seasonal variations in coagulation factors [28,29]. The peak of cancer-associated DVT in summer is a more unique finding. Our data suggests that within the "provoked" category, specific etiologies like cancer may have their own distinct seasonal pattern, possibly related to disease activity, treatment cycles, or patient behavior during different seasons.

Addressing climatic diversity within the study zone: Sousse and Kairouan present distinct climatic profiles—Sousse benefits from a moderating Mediterranean coastal influence, while Kairouan experiences a more extreme continental arid climate [22]. Our subgroup analysis demonstrated that despite these expected meteorological differences (notably in wind speed, humidity, and dew point), the core clinical and epidemiological characteristics of DVT, as well as the key associations with atmospheric pressure and cloud cover, did not differ significantly between residents of the two governorates. This suggests that the observed meteorological associations may be robust across the climatic gradient of central Tunisia. Nevertheless, the limited sample size

from Kairouan (n=20) precludes definitive conclusions, and this limitation is acknowledged.

Impact of the COVID-19 pandemic: Our analysis confirmed a significant 46% increase in monthly DVT incidence during the pandemic period (March 2020–December 2021), consistent with the known prothrombotic effects of SARS-CoV-2 infection, reduced mobility during confinement, and healthcare system disruptions [35,36]. Importantly, adjustment for this period in multivariate models did not alter the primary meteorological associations, suggesting that the weather-DVT relationships observed are independent of pandemic-related confounding.

Extreme climatic events: The summer 2021 heatwave, characterized by record temperatures exceeding 50°C in Kairouan, did not result in a statistically significant increase in DVT cases compared to other summers. While extreme heat can theoretically promote dehydration and hemoconcentration—potential prothrombotic factors—our findings suggest that such events, in isolation, may not substantially modify DVT risk in this population. This observation warrants confirmation in larger studies.

The study has several strengths, including its long duration (13 years), ultrasound confirmation of all DVT cases, statistical validation by an independent biostatistician, and the novel focus on a North African semi-arid context. However, limitations must be acknowledged. It is a single-center study, which may limit generalizability. The sample size, while substantial for a single center, is modest compared to nationwide registry studies, particularly for the Kairouan subgroup. Furthermore, meteorological data were sourced from fixed stations and may not perfectly reflect individual patient exposures. Finally, as a cross-sectional study, causal inference remains limited, and residual confounding by unmeasured factors (e.g., air pollution, seasonal infections, individual physical activity) cannot be excluded.

Conclusion

This study demonstrates a significant and independent association between specific meteorological variables and the occurrence of deep vein thrombosis in central Tunisia. A decrease in atmospheric pressure and an increase in cloud cover were identified as environmental factors associated with a higher risk of DVT. The seasonal pattern of DVT is not monolithic; it varies according to the underlying etiology, with idiopathic cases being more frequent in winter and cancer-associated cases peaking in summer. While the COVID-19 pandemic period was associated with increased DVT incidence, the core meteorological associations remained robust after statistical adjustment.

These findings suggest that weather and seasonal changes may modulate thrombotic risk, but the immediate clinical implications remain speculative. Understanding these environmental influences could inform targeted prevention strategies for high-risk individuals during vulnerable periods. However, further large-scale, multi-center studies are needed to confirm these associations, specifically addressing regional climatic disparities, the interaction between meteorological factors and air pollution, and the impact of health crises such as pandemics.

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