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Original paper

Investigating the correlation between seminal testosterone and cortisol and semen parameters in normozoospermic and teratozoospermic men

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Summary. Male infertility is a growing global concern, affecting even men at their reproductive peak who experience difficulties in achieving conception. Notably, even men classified as normozoospermic according to WHO criteria often face (in/sub)fertility. Hormones such as testosterone and the stress-related cortisol are believed to influence male reproductive function, although their specific roles in semen quality remain incompletely understood. This study aimed to assess testosterone and cortisol concentrations in seminal plasma and investigate their associations with semen quality in normozoospermic (N) and teratozoospermic (T) men. Semen samples were collected from 32 participants (14 N, 18 T) who were eligible for the national assisted reproduction program. Standard semen parameters were analyzed, including sperm count, motility, morphology, viscosity, and the presence of gelatinous material. Hormone levels were measured in the seminal plasma. Group comparisons were performed using the Mann–Whitney test, and associations between variables were evaluated using Spearman's correlation and linear regression analysis. There were no significant differences in seminal plasma testosterone ($p = 0.19$) or cortisol ($p = 0.53$) levels between the N and T groups. In addition, significant differences were observed in sperm count and morphology ($p < 0.0001$) between the groups. In the N group, seminal cortisol levels positively correlated with sperm motility ($r_s = 0.76$), while testosterone levels predicted both sperm motility ($R^2 = 0.2755$, $p = 0.0305$) and viscosity ($R^2 = 0.6069$, $p = 0.0002$). Additionally, a moderate negative correlation was observed between sperm count and gelatinous material in the N group ($r_s = -0.56$). In the T group, notable correlations included testosterone–cortisol ($r_s = 0.87$), morphology–viscosity ($r_s = 0.62$), and a negative correlation between gelatinous material and morphology ($r_s = -0.50$). No significant predictive models were identified in this group. In summary, testosterone and cortisol levels in seminal plasma are important markers of men's reproductive health. Although preliminary due to the limited sample size, these findings suggest a potential modulatory role for seminal testosterone and cortisol in sperm function in men with otherwise normal sperm profiles.

Keywords: cortisol, male infertility, normozoospermia, seminal plasma, spermatozoa, teratozoospermia, testosterone.

INTRODUCTION

Infertility is a global health concern, affecting approximately 15% of couples of reproductive age, with male factors solely or partially contributing to nearly 40–50% of cases, of which for almost 70% the cause is unknown (Agarwal et al. 2021; Wu et al. 2022; Eisenberg et al. 2023; Niederberger 2024). Male infertility is typically defined as the inability to achieve conception after one year of regular, unprotected sexual intercourse and can stem from a wide range of anatomical, hormonal, genetic, and lifestyle-related factors (Bardhi and Drakopoulos 2021; Wei et al. 2024).

Semen analysis remains a cornerstone in the initial evaluation of male infertility and provides critical insights into sperm quality and reproductive potential. The World Health Organization (WHO) has established reference values for key

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semen parameters, including sperm concentration, motility, vitality, and morphology, which are used to distinguish between normozoospermia and pathological conditions (WHO 2021). Normozoospermia (N) refers to semen samples that meet all WHO reference limits, indicating normal sperm production and function. However, even among men with normozoospermic profiles, infertility may persist due to subtle functional or molecular abnormalities not captured by routine semen analysis (Krausz and Riera-Escamilla 2018; Flannigan 2020; Agarwal et al. 2021). In contrast, teratozoospermia (T) is characterized by an abnormally high percentage of morphologically abnormal spermatozoa, often defined by a threshold of <4% normal forms based on strict criteria (WHO 2021). Morphological abnormalities can affect the head, midpiece, or tail of the sperm and are associated with reduced fertilization capacity, impaired sperm-egg interaction, and increased risk of DNA fragmentation (Wu et al. 2022; Eisenberg et al. 2023). Although teratozoospermia can exist in isolation, it frequently co-occurs with other semen abnormalities and has been linked to underlying hormonal or genetic disruptions.

Among the endocrine factors influencing male fertility, testosterone and cortisol have emerged as pivotal regulators. Testosterone, synthesized in the Leydig cells of the testes under the stimulation of luteinizing hormone, is essential not only for the development and maintenance of spermatogenesis, sexual function, and secondary male characteristics, but also for homeostasis of overall health (Krausz and Riera-Escamilla 2018; Flannigan 2020). Deficiencies in testosterone can impair Sertoli cell function and halt spermatogenic progression, often resulting in oligozoospermia, azoospermia, or teratozoospermia (Agarwal et al. 2021; Wu et al. 2022). Conversely, cortisol, a glucocorticoid hormone produced in response to stress via activation of the hypothalamic-pituitary-adrenal axis, exerts a negative influence on reproductive hormones. While short-term cortisol elevations serve protective and adaptive roles, chronic elevations (seen in persistent psychological or physiological stress) can disrupt the hypothalamic-pituitary-adrenal axis and suppress testosterone production (Whirledge and Cidlowski 2010). This suppression has been shown to correlate with impaired spermatogenesis and subfertility in both animal models and human studies (Gómez-Elías et al. 2019; Silva et al. 2022). Furthermore, cortisol exerts a direct negative impact on the testes, potentially inducing oxidative stress, impairing Leydig cell function, and promoting apoptosis in germ cells (Bisht et al. 2017; Silva et al. 2022). Elevated cortisol levels have also been associated with increased levels of reactive oxygen species (ROS), which can damage sperm DNA and reduce parameters critical for successful fertilization, such as motility and viability (Agarwal et al. 2021; Wu et al. 2022). Importantly, testosterone and cortisol exist in reciprocal relationships. This testosterone-to-cortisol ratio has emerged as a potential biomarker of reproductive health. Lower ratios have been associated with reduced semen quality, including poorer sperm morphology and motility (Taitson et al. 2022). The dynamic interplay between these hormones has gained attention in recent years as a potential contributor to male infertility (Gómez-Elías et al. 2019). Notably, even in men with normozoospermia, elevated cortisol or suppressed testosterone may negatively influence fertility by affecting sperm functionality, capacitation, and fertilization potential (Eisenberg et al. 2023; Wei et al. 2024).

In clinical practice, it is increasingly recognized that standard semen parameters may not fully capture the complexity of male infertility. Hormonal profiling (including measurements of cortisol and testosterone) in seminal plasma alongside advanced assessments such as sperm DNA fragmentation tests or oxidative stress markers, may provide a more comprehensive understanding of the underlying etiology, especially in cases of unexplained infertility or isolated teratozoospermia within a normozoospermic context (Agarwal et al. 2021; Kyrgiafini and Mamuris 2023).

Accordingly, our study aimed to assess testosterone and cortisol concentrations in seminal plasma and investigate their associations with semen quality in men with normozoospermia (N) and teratozoospermia (T).

MATERIALS AND METHODS

All experiments were performed in the Laboratory for Reproductive Endocrinology and Signaling and Laboratory for Chronobiology and Aging, Faculty of Sciences, University of Novi Sad (https://wwwold.dbe.pmf.uns.ac.rs/en/nauka-eng/lares).

Ethical approval

Human material used in this study was obtained through pro bono collaboration established with fertility clinics. Ethical approval for the study was granted by the Ethical Committee of the Medical Faculty University of Belgrade (1322/X-10, 10/10/2022) according to the ethical standards laid down in the Declaration of Helsinki. Written informed consent was obtained from all participants.

Study population and participants

Human participants who were used for collecting material were participants entering the national assisted reproductive technology program. It is important to point out that the selection of the participants was done only using the spermiogram's parameters criteria. Although useful, addi-

tional exclusion criteria that could affect semen parameters, such as the patient's medical history, presence of sexually transmitted infections, hormonal imbalances, recent medication use, or lifestyle factors (e.g. smoking, alcohol consumption) were not considered. Only participants with normozoospermic (N) and teratozoospermic (T) diagnosis were selected for the study. Participant recruitment took place from October 2020 to July 2021.

Semen parameter analysis

The seminal samples were analyzed after complete liquefaction at room temperature and manual semen analysis was performed according to the guidelines of the WHO laboratory manual for examining and processing human semen (https://iris.who.int/bitstream/handle/10665/44261/9789241547789_eng.pdf). Routine semen tests were performed to analyze the semen parameters. Samples were further used for the procedure of assisted reproductive technology, while the rest of the sample was centrifuged at 1800 rpm for 5 minutes. The supernatant was transferred to new tubes, frozen at -20°C, and used for the hormone concentrations measurement.

Hormone levels in seminal plasma

Testosterone levels were measured by ECLIA (Electrochemiluminescent Immunoassay) using the cobas e 411 immunoassay analyzer. All samples were measured in duplicate in one assay with a sensitivity range of 0.087-52.0 nmol/L (defined by the Limit of Detection and the maximum of the master curve). For seminal plasma cortisol levels, all samples were measured in duplicate, in one assay by ECLIA using cobas e 411 immunoassay analyzer with a measuring range of 1.5-1750 nmol/L (defined by the Limit of Detection and the maximum of the master curve).

Statistical analysis

Data are presented as group means ± SEM to reflect individual variation, and visualized using box-and-whisker plots. For comparisons within the same group, the Wilcoxon matched-pairs signed-rank test was applied, while comparisons between independent groups were analyzed using the Mann–Whitney U test. Correlations were assessed using Spearman's rank correlation coefficient, and linear regression analysis was performed to explore associations between continuous variables. Prior to analysis, all data were subjected to logarithmic transformation due to non-normal distribution, ensuring the validity of nonparametric and regression methods. All the statistical analyses were performed using GraphPad Prism 8 Software (GraphPad Software 287 Inc., La Jolla, CA, USA). In all cases, a p-value <0.05 was statistically significant.

RESULTS

To understand the correlation between testosterone and cortisol concentrations in seminal plasma and their associations with semen quality in men, the samples of seminal plasma and parameters of spermiograms obtained from men with normozoospermia (N) and teratozoospermia (T) were used.

The levels of testosterone and cortisol in the seminal plasma of normozoospermic and teratozoospermic men

In the normozoospermic group (N = 14), there was no statistically significant difference between testosterone and cortisol concentrations measured within the same samples (Fig. 1A). In contrast, in the teratozoospermic group (T = 18), testosterone levels were significantly lower than cortisol levels ($p = 0.0385$, Fig. 1B). Subsequently, the correlation between these two data were evaluated in both groups using Spearman's correlation coefficient (r_s). Spearman's correlation analysis showed a moderate correlation ($r_s = 0.52$) between testosterone and cortisol levels in the seminal plasma of the normozoospermic group (Fig. 1C), while in the teratoozoospermic group a very strong positive correlation ($r_s = 0.87$, $p < 0.0001$) was observed (Fig. 1D). This finding is further supported by a lower T/C ratio in the teratozoospermic group, potentially indicating a shift toward a catabolic hormonal profile (T/C = 1.11 in N group, T/C = 0.73 in T group).

Correlation of seminal testosterone and cortisol with parameters of spermiogram obtained from normozoospermic and teratozoospermic men

Hormone levels were compared between groups using a Mann-Whitney test, which revealed no statistically significant differences. The same test was applied to spermiogram parameters. Our analysis shows a significant difference in sperm number and morphology ($p < 0.0001$, Fig. 2A), while no significant differences were observed in other examined spermiogram parameters. Spearman's correlation analysis was performed to examine the relationship among hormone levels and spermiogram parameters within each group (Fig. 2B). The results are visualized as a correlation matrix. In normozoospermic group a moderate positive correlation was detected between cortisol and sperm motility ($r_s = 0.76$, $p = 0.002$), while a negative fair correlation was shown between sperm number and gelatinous clamp ($r_s = -0.56$, $p = 0.04$). Meanwhile, in the teratoozoospermic group a very strong correlation was observed between cortisol and testosterone ($r_s = 0.87$, $p < 0.0001$), a moderate correlation between sper-

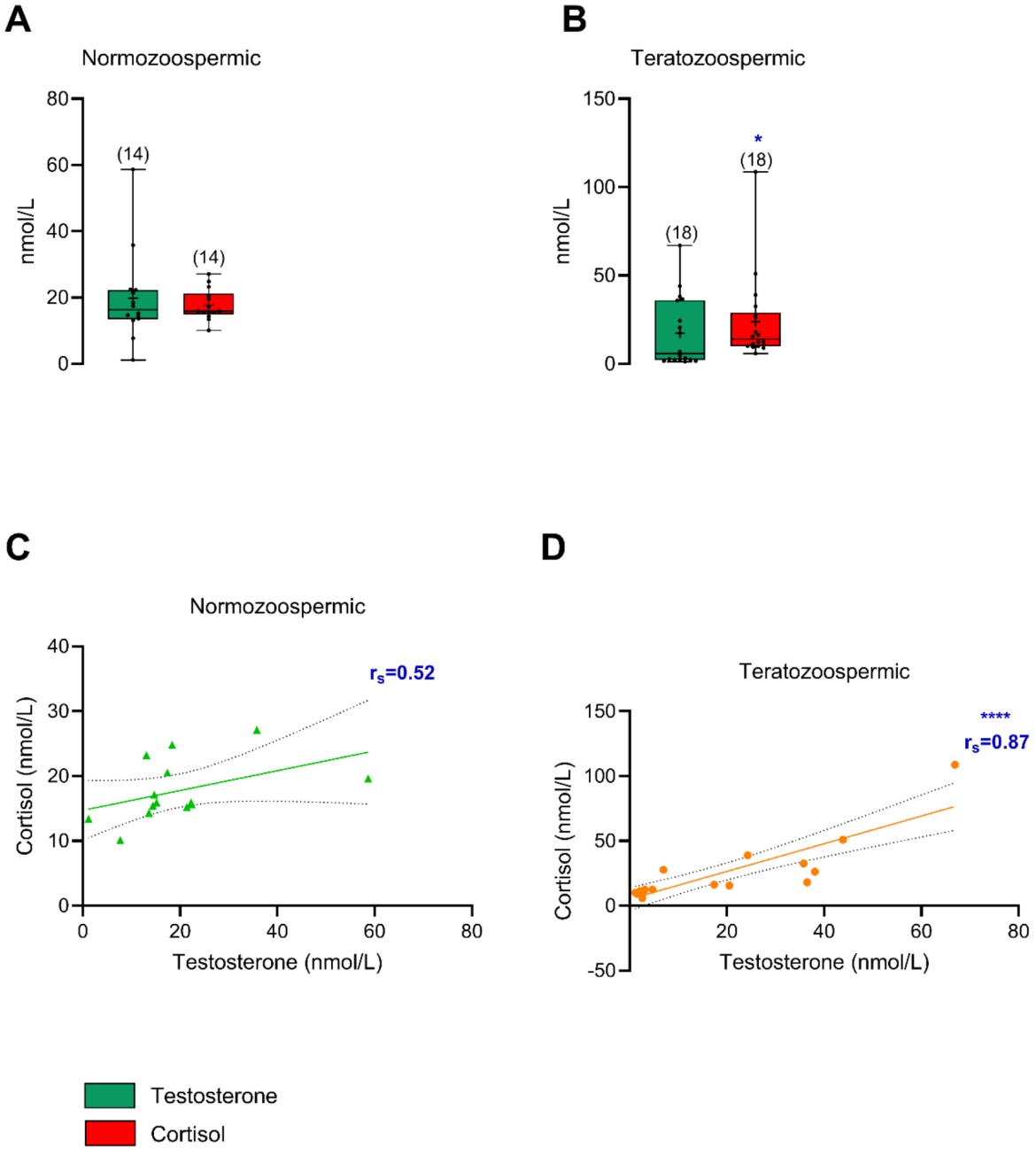

Fig. 1. Correlation of testosterone and cortisol concentrations in seminal plasma of normozoospermic and teratozoospermic men. **A**, Concentration of testosterone and cortisol in normozoospermic men and in **B**, teratozoospermic men, compared using a Wilcoxon matched-pairs test. **C**, Spearman's correlation of testosterone and cortisol in seminal plasma of normozoospermic and **D**, teratozoospermic participants. Cortisol and testosterone in seminal plasma were measured by ECLIA (Eectrochemiluminescence Immunoassay) using cobas e 411 immunoassay analyzer. The Shapiro-Wilk test was used to assess the data distribution. As the data were not normally distributed, non-parametric tests were used. Box and whisker plots show the meaning and the participants' individual values. r_s- indicates Spearman's correlation coefficient. The numbers in the brackets above indicate the number of participants per group. Statistical significance was set at $p < 0.05$.

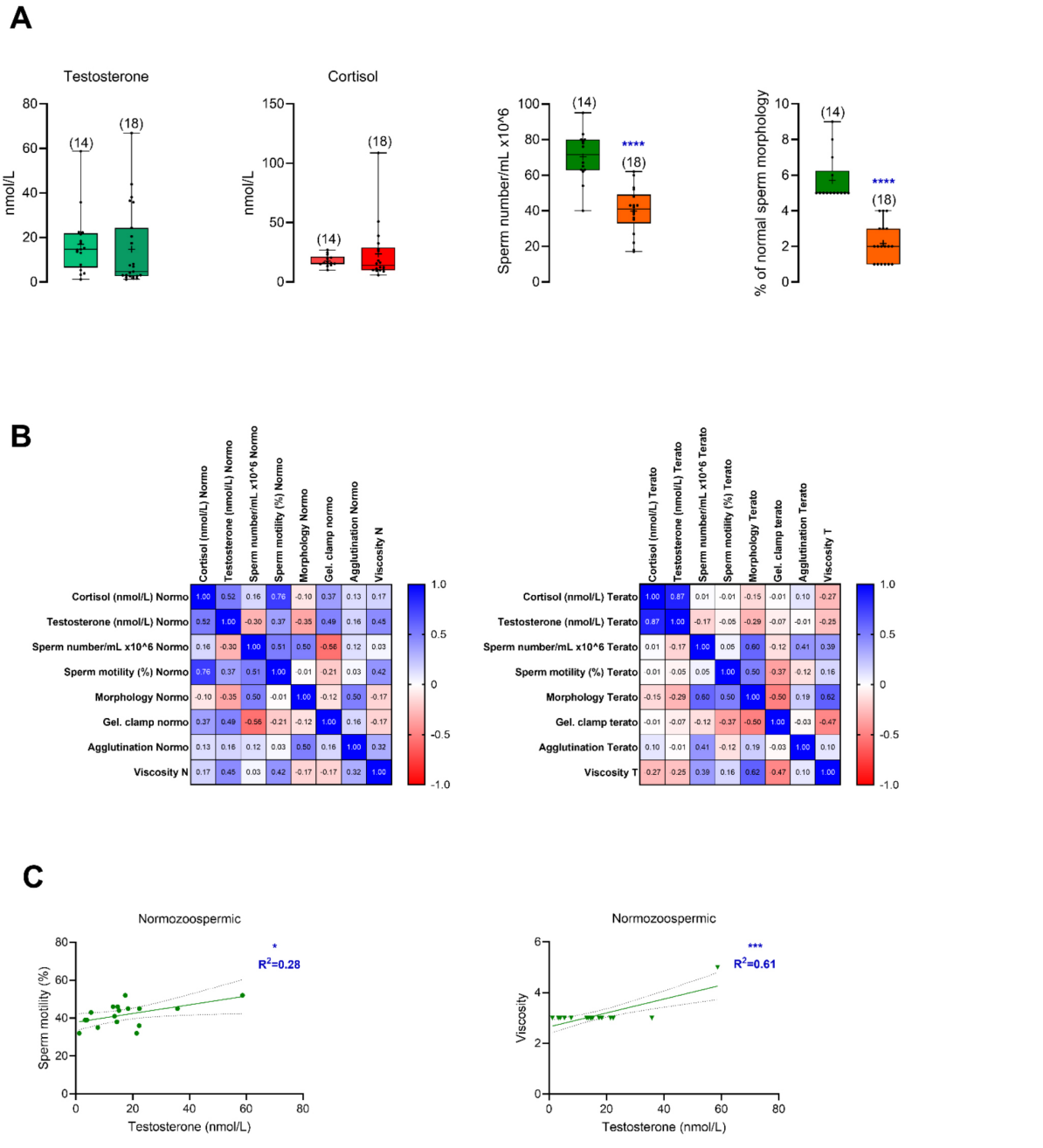

Fig. 2. Comparative analysis of hormonal levels and semen parameters between normozoospermic and teratozoospermic groups and their associations. **A**, A non-parametric Mann-Whitney U test is used for comparison of hormonal levels and semen parameters in normozoospermic and teratozoospermic men. A statistically significant reduction in sperm number and the percentage of morphologically normal spermatozoa was observed in the teratozoospermic group compared to normozoospermic ($p < 0.0001$). **B**, Correlation matrices illustrate associations between hormonal levels and semen parameters within each group. Spearman coefficient (r_s) is color coded, blue showing positive correlation and red showing negative correlation. The moderate correlation in normozoospermic group is observed between cortisol and sperm motility ($r_s = 0.76$, $p = 0.002$), while the negative fair correlation in the same group is detected between sperm number and gelatinous clamp ($r_s = -0.56$, $p = 0.04$). Meanwhile, in the teratozoospermic group, a very strong correlation was observed between cortisol and testosterone ($r_s = 0.87$, $p < 0.0001$), a moderate correlation between spermatozoa with normal morphology and viscosity ($r_s = 0.62$, $p = 0.006$), and a negative fair correlation between gelationous clamp and spermatozoa with normal morphology ($r_s = -0.50$, $p = 0.034$). Linear regression **C**, shows positive relationship of testosterone levels with sperm motility and viscosity in normozoospermic men. Stronger association is found between testosterone and viscosity ($R^2 = 0.61$, $p = 0.0002$) while testosterone has a weaker association with sperm motility ($R^2 = 0.28$, $p = 0.03$). Statistical significance was set at level $p < 0.05$.

matozoa with normal morphology and viscosity (r_s = 0.62, p = 0.006), and a negative fair correlation between gelationous clamp and spermatozoa with normal morphology (r_s = -0.50, p = 0.034).

Seminal testosterone and cortisol: potential biomarkers of semen quality in normozoospermic and teratozoospermic men

Based on the initial correlation findings, a linear regression analysis was conducted to determine whether hormonal levels contribute to variations in semen parameters (Fig. 2C). In the normozoospermic group, a positive relationship of testosterone levels with sperm motility and viscosity was determined. Stronger association was found between testosterone and viscosity (R^2 = 0.61, p = 0.0002) while the testosterone has weaker association with sperm motility (R^2 = 0.28, p = 0.03). No associations were found in teratozoospermic group.

DISCUSSION

Male infertility is a heterogeneous condition where hormonal balance, particularly involving cortisol and testosterone, plays a central role in determining semen quality, including sperm morphology and function. Understanding the interplay between these hormones and their association with normozoospermia and teratozoospermia can help improve diagnostic accuracy and inform more targeted treatment strategies.

The present study provides insights into the complex interplay between seminal testosterone and cortisol levels and semen quality in normozoospermic and teratozoospermic men (Fig. 3). Although the seminal concentrations of these hormones did not differ significantly between the two groups, the significant correlation between testosterone and cortisol levels in seminal plasma was observed only in the teratozoospermic group, while in the normozoospermic group correlation was not significant. The significant correlation between seminal testosterone and cortisol levels in the teratozoospermic group may suggest potential functional roles in modulating sperm physiology, even in the absence of overt hormonal imbalances.

The lack of significant differences in testosterone and cortisol concentrations between normozoospermic and teratozoospermic men is consistent with prior observations that conventional hormone levels may not always reflect subtle endocrine influences on sperm function (Carlsen et al. 2005; Dohle et al. 2010). Nonetheless, the observed strong positive correlation between testosterone and cortisol in both groups underscores a tightly regulated intra-seminal hormonal milieu, possibly indicative of a coordinated endocrine response relevant for reproductive homeostasis (Tilbrook et al. 2000).

In normozoospermic men, seminal cortisol levels showed a significant yet moderate positive correlation with sperm motility (r_s = 0.76), a finding that aligns with evidence suggesting that glucocorticoids at physiological levels may play supportive roles in sperm maturation and energy metabolism (Whirledge and Cidlowski 2010). The predictive value of testosterone for sperm motility (R^2 = 0.2755) and seminal viscosity (R^2 = 0.6069) further highlights the androgenic influence on epididymal function and seminal plasma composition, both critical for sperm transport and fertilization potential (Kondarewicz et al. 2022).

Interestingly, the negative and weak correlation (r_s=-0.56) between sperm count and the presence of gelatinous material in the normozoospermic group suggests that the biophysical characteristics of seminal fluid, including its viscosity and coagulation, may not serve as indirect markers of spermatogenic output. This association is biologically plausible given that seminal vesicle secretions contribute both to seminal volume and to the gelatinous fraction of the ejaculate and are influenced by androgens (Rodriguez-Martinez 2003).

In contrast, the teratozoospermic group exhibited a different pattern of associations. A robust testosterone–cortisol correlation (r_s = 0.87) was present, which may reflect a common regulatory axis or stress-induced modulation in the testicular or accessory gland environment. However, the lack of predictive power for hormone levels in relation to sperm parameters in this group suggests a disrupted or less efficient hormonal regulation of sperm maturation and quality in the presence of morphological abnormalities. The significant correlation between sperm morphology and viscosity (r_s = 0.62) may reflect changes in the biochemical environment of the seminal plasma that adversely affect sperm morphology, while the negative correlation between gelatinous material and morphology (r = -0.50) could indicate an imbalance in seminal coagulation dynamics or secretory function of accessory glands in these individuals (Tvrda et al. 2015).

Despite the small sample size, the data presented here emphasize the potential utility of seminal cortisol and testosterone measurements as supplementary markers of sperm function, particularly in normozoospermic individuals who present with unexplained subfertility. The findings support the hypothesis that local hormone concentrations in the seminal plasma, rather than systemic levels alone, may provide more physiologically relevant insights into male fertility status (Behre et al. 1997; Fraczek and Kurpisz 2015).

The implications of these findings are twofold. First, they highlight the need for a more nuanced evaluation of normozoospermic men in infertility assessments, as traditional semen analysis may overlook underlying hormonal or biochemical disruptions that affect fertility potential. Second, they suggest that integrating seminal hormonal pro-

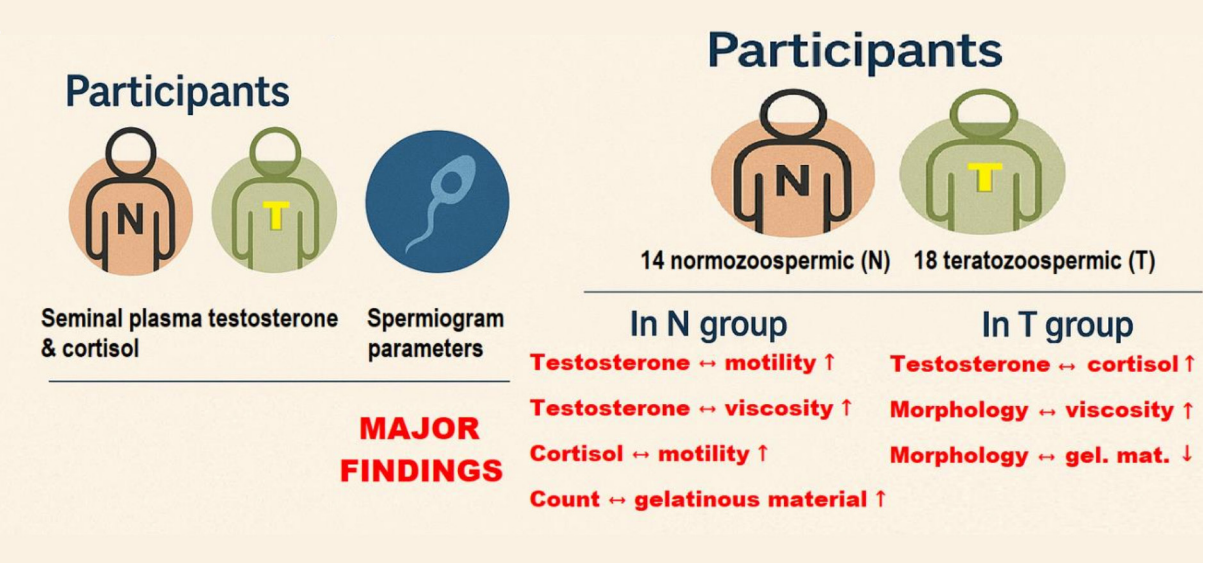

Fig. 3. Seminal testosterone and cortisol: potential modulators of sperm function in normozoospermic and teratozoospermic men.

filing with conventional semen parameters could enhance diagnostic sensitivity and inform individualized therapeutic strategies, such as antioxidant, anti-inflammatory, or hormonal modulation therapies (Aitken and Roman 2008).

Future research with larger cohorts and longitudinal designs is warranted to validate these preliminary associations and to elucidate the mechanistic underpinnings of hormone–sperm interactions in both fertile and infertile men. Moreover, incorporating molecular biomarkers, oxidative stress indices, and assessments of the hypothalamic–pituitary–gonadal axis could provide deeper insights into the etiopathogenesis of male infertility across the sperm morphology spectrum.

The clinical relevance of this hormonal interplay is significant (Segupta et al. 2021). Men exposed to chronic stress, untreated depression, night shift work, or metabolic disorders often exhibit elevated cortisol and suboptimal testosterone levels, conditions which correlate with reduced semen quality, decreased libido, and impaired reproductive capacity (Gómez-Elías et al. 2019; Taitson et al. 2022; Eisenberg et al. 2023). Therapeutic strategies aimed at reducing cortisol levels (through stress management, lifestyle interventions, or pharmacological approaches) may help restore hormonal homeostasis and improve fertility outcomes in selected individuals.

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Data availability statement

All relevant data and samples are available from the corresponding author on request. Further information and requests for resources and reagents should be directed to and will be fulfilled by the Lead Contact, Silvana Andric (silvana.andric@dbe.uns.ac.rs).

Author's contributions statement

T.D.B. – acquisition of the data; analysis and interpretation of the data; drafting the manuscript; revising manuscript critically for important intellectual content; final approval of the version to be submitted; I.M.K. – acquisition of the data; analysis and interpretation of the data; revising manuscript critically for important intellectual content; final approval of the version to be submitted; S.M.R.P. – acquisition of the data; analysis and interpretation of the data; revising manuscript critically for important intellectual content; final approval of the version to be submitted; T.S.K. – acquisition of the data; analysis and interpretation of the data; revising manuscript critically for important intellectual content; final approval of the version to be submitted; S.A.A. – the con-

ception and design of the research; acquisition of the data; analysis and interpretation of the data; drafting the manuscript; revising manuscript critically for important intellectual content; final approval of the version to be submitted. All authors - approved the final version of the manuscript agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved; qualify for authorship, and all those who qualify for authorship are listed.

Conflict of interest statement

The authors declare no competing interests.

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