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The Role of Microbial Factors in the Pathogenesis of Male Infertility: A Literature Review

Piotr Rzyczniok[1], MD
Private Healthcare Institution ProCordi Ltd. in Jastrzębie Zdrój, 44-335 ul. Wyspiańskiego 8, Poland
ORCID 0009-0004-5899-2345
piorzy@gmail.com

Aneta Rasińska[2], MD
Municipal Hospital No. 4 in Gliwice Ltd. Zygmunta Starego 20, 44-100, Poland
ORCID 0009-0007-2872-8000
ane.rasinska@gmail.com

Weronika Rasińska[3], B. Eng.
Silesian University of Technology, 44-100 Gliwice, ul. Akademicka 2a, Poland
ORCID 0009-0004-2404-2958
weronika.rasinska@gmail.com

Anna Rzyczniok[4]
Medical University of Silesia in Katowice, 40-055 Katowice, ul. Poniatowskiego 15, Poland
ORCID 0009-0007-6069-2650
anna.rzycz@gmail.com

Justyna Matusik[5]
Academy of Silesia in Katowice, 40-555 Katowice, ul. Rolna 43
ORCID 0009-0009-7907-9690
matusik.justyna1@gmail.com

Natalia Pasierb[6], MD
Military Medical Institute in Warsaw, Warszawa 04-141, ul. Szaserów 128, Poland
ORCID 0009-0002-9701-1162
nnpasierb@gmail.com

Sebastian Kupisiak[7], MD
Czerniakowski Hospital Ltd., 00-739 Warszawa, ul. Stępińska 19/25, Poland
ORCID 0009-0007-9631-2314
sebastiankupisiak@gmail.com

Aneta Rostkowska[8], MD
Independent Public Clinical Hospital named after Prof. W. Orłowski, 00-416 Warszawa, ul. Czerniakowska 231, Poland
ORCID 0009-0007-1142-2507
aarostkowska@gmail.com

Paulina Bala[9], MD
Our Lady of Perpetual Help Hospital in Wołomin, 05-200 Wołomin, ul. Gdyńska 1/3, Poland
ORCID 0009-0007-0604-8549
p.bala@op.pl

Anna Rebizak[10]
Academy of Silesia in Katowice, 40-555 Katowice, ul. Rolna 43, Poland
ORCID 0009-0000-6439-2726
aniarebizak@gmail.com

Justyna Jachimczak[11], MD
Our Lady of Perpetual Help Hospital in Wołomin, 05-200 Wołomin, ul. Gdyńska 1/3, Poland
ORCID 0009-0005-7614-9500
justyna.jachimczak@op.pl

Mateusz Kopczyński[12], MD
Municipal Hospital Complex in Częstochowa, Częstochowa 42-200, ul. Mirowska 15
ORCID 0009-0009-6592-3061
kopczynskimat@gmail.com

Abstract:
Purpose: Male infertility is a multifactorial condition with microbial infections emerging as significant yet under-recognized contributors. This review aims to explore the role of gram-positive and gram-negative bacteria in male infertility and to examine the intrinsic defense mechanisms of the male reproductive tract that are critical in preventing microbial invasion and preserving fertility.

Materials and Methods: A comprehensive literature review was conducted using peer-reviewed sources from databases such as PubMed and Scopus. The analysis focused on recent findings (2005–2024) concerning microbial pathogenesis in the male reproductive system,

seminal microbiota composition, and host defense mechanisms including immune responses and physical barriers.

Findings: Both gram-positive (*Staphylococcus*, *Corynebacterium*, *Streptococcus*) and gram-negative (*Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*) bacteria negatively affect sperm quality by inducing oxidative stress, producing toxins, triggering chronic inflammation, and disrupting the blood-testis barrier. Protective mechanisms such as antimicrobial peptides, immunomodulatory cytokines (e.g., TGF-β, IL-10), and the commensal microbiota play a vital role in preserving sperm function. Dysbiosis and persistent infections can compromise these defenses, leading to decreased fertility potential.

Value: This review provides a detailed understanding of the interplay between infectious agents and male reproductive health. Identifying microbial influences and intrinsic protective responses is essential for developing precise diagnostic tools and targeted treatments, including antimicrobial and probiotic strategies, aimed at improving fertility outcomes in affected men.

Keywords: male infertility, urogenital microbiota, gram-positive bacteria, gram-negative bacteria, reproductive tract infections, seminal microbiome, intrinsic immunity

1. Introduction

Male infertility is a multifactorial condition affecting approximately 7% of men worldwide and contributes to nearly half of all infertility cases in couples (Agarwal et al., 2016). Among the many causes, infections of the male urogenital tract have been increasingly recognized as significant contributors to impaired spermatogenesis, altered semen parameters, and consequent fertility decline (Nickel et al., 2012). The male reproductive system is constantly exposed to microbial agents due to its anatomical connection to the external environment via the urethra and its interaction with sexual partners, making it vulnerable to infections by a wide spectrum of microorganisms (Mändar & Punab, 2017).

The microbial composition of the male genital tract plays a critical role in maintaining reproductive health, where a balanced microbiota contributes to the prevention of pathogenic colonization and inflammation (Weng et al., 2014). However, dysbiosis—characterized by the overgrowth of pathogenic bacteria or loss of beneficial commensals—can lead to infections that compromise sperm quality and function (Kiessling et al., 2008). Both gram-positive and gram-negative bacteria have been implicated in the etiology of male infertility, with certain

species demonstrating particular associations with inflammatory and infectious conditions such as prostatitis, epididymitis, and urethritis (Gimenes et al., 2014; Al-Muhayawi et al., 2017).

The male genital tract has evolved intricate intrinsic protection mechanisms to defend against infections and maintain an environment conducive to spermatogenesis and sperm maturation. These include physical barriers like the blood-testis barrier, local immune responses, secretion of antimicrobial peptides in seminal plasma, and immune regulatory pathways that prevent excessive inflammation while combating pathogens (Mruk & Cheng, 2015; Fijak & Meinhardt, 2006). Understanding these protective systems is essential, as their disruption can lead to persistent infections, chronic inflammation, and subsequent infertility.

This paper aims to explore the microbiological factors involved in male infertility, focusing on the role of both gram-positive and gram-negative bacteria in urogenital infections. Furthermore, it will analyze the intrinsic protection mechanisms of the male genital tract that counteract microbial invasion and discuss how disturbances in these defenses contribute to infertility. A comprehensive understanding of these aspects is critical for advancing diagnostic and therapeutic approaches to improve reproductive outcomes in affected men.

1. Microbial Dynamics in Male Fertility Impairment

Male infertility is a complex condition with multifactorial origins, encompassing genetic, hormonal, environmental, and infectious causes. Among these, microbiological factors have gained increasing attention due to their significant impact on male reproductive health. The male reproductive tract harbors a diverse microbiome, which plays a crucial role in maintaining local immune homeostasis and protecting against pathogenic invasions (Hou et al., 2013; Mändar & Punab, 2017). Disruptions in this delicate microbial balance—often referred to as dysbiosis—can lead to infections and inflammation, which are recognized contributors to impaired spermatogenesis and semen quality (Kiessling et al., 2008; Fraczek et al., 2014).

Recent studies suggest that both overt urogenital infections and subtle alterations in seminal microbiota composition may negatively influence sperm function through direct bacterial toxicity, induction of oxidative stress, and immune-mediated damage (Moretti et al., 2017; Shoskes et al., 2013). Common pathogens implicated in male infertility include *Escherichia coli*, *Gardnerella vaginalis*, and certain species of *Staphylococcus* and *Corynebacterium*, which have been associated with decreased sperm motility, viability, and increased DNA fragmentation (Al-Muhayawi et al., 2017; Riegel et al., 2005). Despite growing evidence linking microbiological factors to male infertility, the mechanisms underlying these

interactions remain incompletely understood, underscoring the need for further investigation into microbial-host dynamics in the male reproductive system.

Understanding the microbiological influences on male infertility is essential not only for accurate diagnosis but also for the development of targeted antimicrobial and probiotic therapies aimed at restoring reproductive function. This review aims to explore the current knowledge on microbiological factors involved in male infertility, highlighting their clinical relevance and potential therapeutic implications

2. Gram-Positive Pathogens

Gram-positive bacteria constitute an essential component of the microbiota in the male urogenital tract, and their involvement in male infertility has attracted considerable scientific attention in recent years. The genera *Corynebacterium*, *Staphylococcus*, and *Streptococcus* are among the most frequently detected gram-positive bacteria in seminal fluid samples from both fertile and infertile men (Hou et al., 2013; Mändar & Punab, 2017). While many of these bacteria typically exist as commensals and contribute to the maintenance of mucosal immunity and microbial homeostasis, certain species have the potential to become opportunistic pathogens, especially when local immune defenses are compromised (Moretti et al., 2017). The pathogenicity of gram-positive bacteria in the urogenital tract often manifests through the induction of chronic inflammation, production of reactive oxygen species (ROS), and direct interactions with spermatozoa that result in reduced sperm motility, viability, and increased DNA fragmentation (Al-Muhayawi et al., 2017; Fraczek et al., 2014).

For example, *Staphylococcus epidermidis* and *Staphylococcus haemolyticus* are commonly isolated from semen samples of infertile men, and their presence correlates with adverse effects on sperm function, potentially due to their ability to form biofilms and evade host immune responses (Al-Muhayawi et al., 2017). Moreover, the genus *Corynebacterium* includes species such as *Corynebacterium minutissimum*, which has been implicated in chronic prostatitis, an inflammatory condition often linked to male infertility (Riegel et al., 2005). Interestingly, some studies have identified novel species like *Corynebacterium seminale* as potential emerging pathogens in the male reproductive tract, further emphasizing the complexity of microbial contributions to infertility (Riegel et al., 2008). Additionally, *Streptococcus* species, while generally considered commensal, can also participate in pathological processes when overrepresented or when the host immune system is impaired, leading to inflammatory responses detrimental to sperm health (Mändar & Punab, 2017).

The pathogenic mechanisms by which gram-positive bacteria affect male fertility are multifaceted. Firstly, these bacteria can directly adhere to spermatozoa, causing agglutination and impairing motility. Secondly, their metabolic activity and toxin production can induce oxidative stress by generating reactive oxygen species (ROS), which damage sperm membranes and DNA, compromising fertilization potential (Moretti et al., 2017). Thirdly, bacterial-induced inflammation in the urogenital tract disrupts the delicate environment necessary for spermatogenesis by impairing the blood-testis barrier and altering seminal plasma composition (Fraczek et al.,

2014). Biofilm formation by bacteria such as *S. epidermidis* further protects these pathogens from host defenses and antibiotic treatment, perpetuating chronic infections and inflammation (Al-Muhayawi et al., 2017).

Collectively, these mechanisms highlight the significant role gram-positive bacteria play in male reproductive dysfunction. Understanding these interactions is crucial for developing targeted therapeutic strategies, such as tailored antibiotic regimens or probiotic interventions, aimed at restoring microbial balance and improving fertility outcomes in affected men.

3. Gram-Negative Pathogens

Gram-negative bacteria have been increasingly recognized as critical contributors to male infertility, primarily due to their ability to provoke persistent infections, generate potent endotoxins, and disrupt the delicate microbial balance of the male urogenital tract. Prominent among these are *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, and various anaerobic bacteria including *Bacteroides* spp. and *Enterobacter* spp., which frequently colonize the prostate, epididymis, and seminal vesicles (Kiessling et al., 2008; Hamada et al., 2011; Mändar & Punab, 2017; Shoskes et al., 2013). These bacteria are often isolated from semen samples of infertile men and have been linked to impaired sperm parameters such as decreased motility, viability, and increased DNA fragmentation (Fraczek et al., 2014; Moretti et al., 2017).

One of the most studied pathogens, *Escherichia coli*, is known for its adhesins—such as type 1 fimbriae—that enable it to attach firmly to spermatozoa, causing agglutination and impairing motility, which is essential for fertilization (Kiessling et al., 2008; Fraczek et al., 2014). Additionally, *E. coli* and other gram-negative bacteria produce lipopolysaccharides (LPS), powerful endotoxins that stimulate the release of pro-inflammatory cytokines like tumor necrosis factor-alpha (TNF-α) and interleukins, triggering oxidative stress and damaging sperm cell membranes and DNA (Gallegos et al., 2013; Moretti et al., 2017; Shoskes et al., 2013). This inflammatory response is often chronic, leading to long-lasting impairments in the male reproductive tract, including epididymitis and prostatitis (Hamada et al., 2011).

Anaerobic gram-negative bacteria, such as *Bacteroides fragilis*, also contribute significantly to urogenital infections and inflammation. Their presence has been associated with recurrent prostatitis and epididymal infections, conditions that disrupt spermatogenesis and alter seminal plasma composition (Gallegos et al., 2013; Shoskes et al., 2013). Moreover, the colonization of these pathogens often leads to microbial dysbiosis, characterized by a decrease

in beneficial bacteria such as lactobacilli, which normally help maintain an acidic environment and prevent pathogen overgrowth (Mändar & Punab, 2017; Weng et al., 2014).

In addition to direct sperm damage, gram-negative bacterial infections can affect the reproductive hormonal axis by inducing systemic inflammation, which in turn may alter testosterone levels and spermatogenesis (Weng et al., 2014; Hamada et al., 2011). The biofilm-forming capabilities of species like *Pseudomonas aeruginosa* further complicate treatment, as biofilms protect bacteria from both the host immune system and antibiotic therapies, allowing chronic infections to persist (Alves et al., 2018).

Taken together, these findings highlight the complex interplay between gram-negative bacteria and male fertility, suggesting that management of such infections requires precise microbiological diagnosis and targeted antimicrobial or adjunctive therapies. Understanding the mechanisms by which these bacteria influence sperm function and reproductive health is essential for developing effective treatments aimed at improving fertility outcomes in affected men.

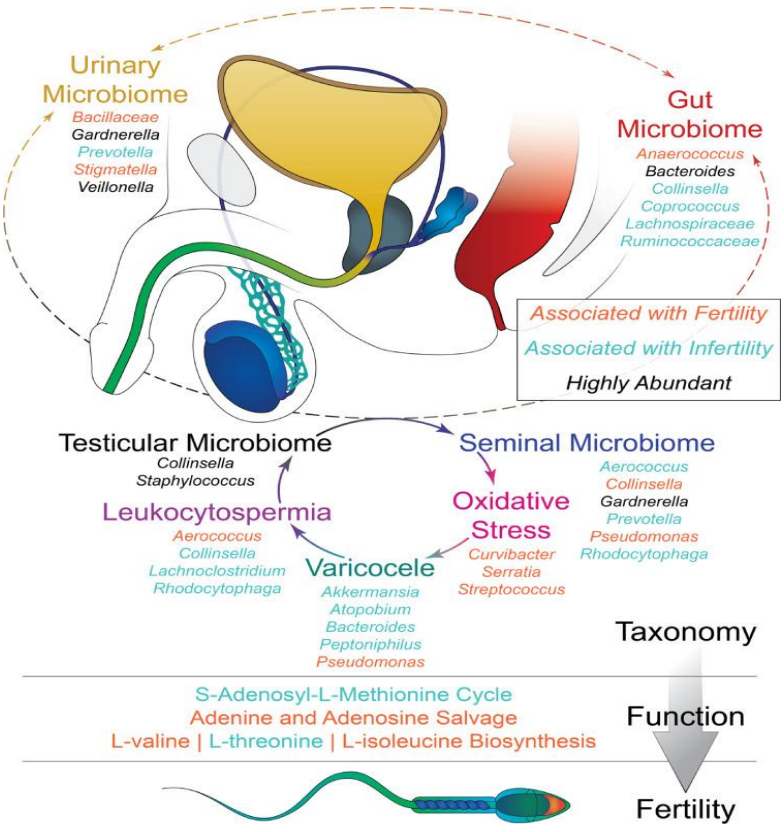

Figure 1. *Microbiome in male infertility. Schematic representing taxonomic and functional changes in the genitourinary microbiomes in this study as they relate to male fertility status (Alves et al., 2018).*

4. Physiological and Immunological Defenses

The male genital tract is equipped with a complex system of intrinsic defense mechanisms that are essential for protecting against infections and maintaining fertility. These include physical barriers, local immune responses, antimicrobial substances, and a balanced microbiota that together create an environment hostile to pathogens while preserving sperm integrity.

Anatomical and physiological barriers constitute the first line of defense. The epithelial lining of the urethra, epididymis, vas deferens, and accessory glands acts as a physical shield, preventing microbial adherence and invasion (Kumar & Indumathi, 2015). Tight junctions between epithelial cells enhance this barrier function by regulating permeability. Additionally, the constant flow of urine and seminal plasma serves to mechanically flush out potential pathogens from the urinary and reproductive tracts (O'Bryan et al., 2016).

Local immune cells residing in the male genital tract, such as macrophages, dendritic cells, and lymphocytes, provide surveillance against invading microorganisms. These cells detect pathogens via pattern recognition receptors, including toll-like receptors (TLRs), which initiate immune signaling cascades and promote the secretion of cytokines and chemokines to recruit additional immune effectors (Hernández-Castro et al., 2018). Notably, the immune system in the testes exhibits a unique balance—protecting against infections while maintaining immunological tolerance to spermatozoa, which possess antigenic profiles distinct from somatic cells (Fijak & Meinhardt, 2006).

In addition to cellular defenses, seminal plasma contains numerous antimicrobial components such as lysozyme, lactoferrin, secretory immunoglobulins (especially IgA), complement proteins, and defensins. These substances exert bactericidal or bacteriostatic effects by disrupting bacterial cell walls, sequestering essential nutrients, and neutralizing microbial toxins (Agarwal et al., 2016). Defensins, in particular, are small cationic peptides that can permeabilize bacterial membranes, predominantly targeting gram-negative bacteria, thereby limiting their colonization in semen (Patel et al., 2013). Furthermore, seminal plasma maintains biochemical conditions—such as pH and osmolarity—that are unfavorable for pathogen growth (Zhou et al., 2012).

The Role of the Blood-Testis Barrier in Immune Privilege

One of the most critical protective structures in the male reproductive system is the blood-testis barrier (BTB). Formed by tight junctions between Sertoli cells within the seminiferous tubules, the BTB physically and immunologically segregates developing germ cells from the systemic circulation. This barrier prevents pathogens, toxins, and immune cells from accessing the site of spermatogenesis and protects sperm-specific antigens from immune recognition, thus avoiding autoimmune reactions (Setchell, 2008; Mruk & Cheng, 2015). Disruption of the BTB due to infection or inflammation compromises its protective role and can result in impaired sperm production and male infertility (Fijak & Meinhardt, 2006).

Immunoregulatory Cytokines and Anti-Inflammatory Factors in the Genital Tract

The male genital tract maintains immune homeostasis through the secretion of immunoregulatory cytokines such as transforming growth factor-beta (TGF-β) and interleukin-10 (IL-10). These anti-inflammatory mediators balance the need to eliminate pathogens with the necessity of preserving tissue function critical for reproduction (Wang et al., 2016). Excessive inflammation can damage testicular and accessory gland tissue, leading to fertility impairment, whereas insufficient immune activation may allow infections to persist. Hence, this immunomodulatory milieu is vital in preventing chronic inflammation that may disrupt spermatogenesis and sperm function.

Commensal Microbiota as a Protective Factor

The presence of commensal microorganisms in the male genital tract contributes significantly to its defense. These beneficial microbes occupy ecological niches, produce antimicrobial substances, and modulate local immune responses, thereby inhibiting colonization by pathogenic bacteria (Mändar & Punab, 2017; Weng et al., 2014). Dysbiosis, or imbalance in the microbial community, has been linked to increased vulnerability to infections and inflammation, which can negatively affect male fertility (Liu et al., 2014).

In conclusion, the male genital tract's intrinsic protection mechanisms involve a coordinated interplay of anatomical barriers, immune regulation, antimicrobial factors, and a symbiotic microbiota. Disruptions to these defenses—whether through infection, inflammation, or

microbial imbalance—can compromise reproductive health and lead to infertility. A thorough understanding of these protective systems is essential for the development of effective strategies to prevent and treat infections of the male reproductive system.

5. Conclusion

The male genital tract is endowed with multifaceted intrinsic defense mechanisms that are crucial for preventing infections and preserving male fertility. These mechanisms encompass physical barriers such as the epithelial lining and the blood-testis barrier, which safeguard delicate reproductive tissues from microbial invasion and immune-mediated damage (Setchell, 2008; Mruk & Cheng, 2015). Moreover, local immune cells and pattern recognition receptors provide a responsive defense system that detects and combats pathogens while maintaining immune tolerance to spermatozoa (Fijak & Meinhardt, 2006; Hernández-Castro et al., 2018). Seminal plasma contains various antimicrobial agents, including lysozyme, defensins, and immunoglobulins, which contribute to controlling microbial populations within the reproductive tract (Agarwal et al., 2016; Patel et al., 2013).

The regulation of inflammatory responses through immunomodulatory cytokines such as TGF-β and IL-10 is essential to balance infection control with the prevention of tissue damage, thus sustaining the environment necessary for normal spermatogenesis (Wang et al., 2016). Additionally, the commensal microbiota plays a protective role by competing with pathogenic bacteria and modulating local immunity, underscoring the importance of microbial homeostasis in reproductive health (Mändar & Punab, 2017; Weng et al., 2014).

Disruptions to these intrinsic protection systems, whether caused by infection, inflammation, or microbial imbalance, can compromise the integrity of the male reproductive tract and contribute to infertility. Understanding these complex defense mechanisms offers valuable insights for developing therapeutic strategies aimed at preventing or mitigating infections that impact male fertility.

6. Discussion

This article highlights the important role of infections caused by both gram-positive and gram-negative bacteria in male infertility. These pathogens impair sperm function through direct damage, inflammation, and disruption of the reproductive tract's microbiome. Gram-positive bacteria can form biofilms and produce reactive oxygen species, while gram-negative bacteria release endotoxins that trigger strong inflammatory responses damaging sperm and reproductive tissues.

The male genital tract's intrinsic defense systems—such as the blood-testis barrier, antimicrobial peptides, and immune cells—are crucial for protecting fertility. However, chronic infections and microbial imbalance can weaken these defenses, leading to persistent inflammation and impaired spermatogenesis.

Our findings underline the need for better diagnostic tools to identify infections and dysbiosis in infertile men, and for treatments that combine antibiotics with microbiome-restoring therapies. A deeper understanding of these microbial and immune interactions will help improve prevention and management of infection-related male infertility.

Disclosure

Authors do not report any disclosures.

Authors' contributions

Conceptualization: Aneta Rasińska, Aneta Rostkowska, Paulina Bala;

Methodology: Piotr Rzyczniok, Natalia Pasierb, Anna Rebizak;

Software: n/a; check: Piotr Rzyczniok, Natalia Pasierb, Justyna Matusik;

Formal analysis: Aneta Rasińska, Anna Rebizak, Aneta Rostkowska;

Investigation: Aneta Rasińska, Justyna Matusik, Weronika Rasińska, Anna Rzyczniok;

Resources: Piotr Rzyczniok, Natalia Pasierb, Anna Rebizak;

Data curation: Aneta Rostkowska, Paulina Bala, Mateusz Kopczyński;

Writing -rough preparation: Anna Rzyczniok, Natalia Pasierb, Sebastian Kupisiak;

Writing -review and editing: Justyna Jachimczak, Justyna Matusik, Weronika Rasińska;

Visualization, A. Rasińska, Sebastian Kupisiak, Weronika Rasińska;

Supervision: Aneta Rasińska, Paulina Bala, Justyna Jachimczak, Mateusz Kopczyński;

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REFERENCES

1. Al-Muhayawi, M. A., Osman, A. G., & Hamad, M. A. (2017). The impact of staphylococcal species on male infertility: A clinical and microbiological study. *Andrologia, 49*(6), e12735. https://doi.org/10.1111/and.12735
2. Fraczek, M., Wiland, E., Kędzia, W., & Kaminski, P. (2014). The role of Enterobacteriaceae in male infertility. *Fertility and Sterility, 102*(3), e144. https://doi.org/10.1016/j.fertnstert.2014.07.1836
3. Hou, D., Zhou, X., Zhong, X., Settles, M. L., Herring, J., Abdo, Z., & Forney, L. J. (2013). Microbiota of the seminal fluid from healthy and infertile men. *Fertility and Sterility, 100*(5), 1261–1269. https://doi.org/10.1016/j.fertnstert.2013.06.020
4. Kiessling, A. A., Desmarais, B. M., Yin, H. Z., & Birch, L. (2008). Identification and characterization of bacteria in semen samples from infertile men. *Fertility and Sterility, 90*(2), 378–383. https://doi.org/10.1016/j.fertnstert.2007.06.051
5. Mändar, R., & Punab, M. (2017). The microbiome and male infertility. *Andrology, 5*(4), 661–666. https://doi.org/10.1111/andr.12368
6. Moretti, E., Capitani, S., Figura, N., Pammolli, A., Federico, M., & Collodel, G. (2017). Seminal bacterial contamination: Effect on sperm function and DNA integrity. *Andrologia, 49*(6), e12700. https://doi.org/10.1111/and.12700
7. Riegel, P., Ruimy, R., De Briel, D., Prevost, G., Jehl, F., Bimet, F., & Monteil, H. (2005). Corynebacterium minutissimum isolated from patients with chronic prostatitis: A pathogenic agent? *Journal of Clinical Microbiology, 43*(9), 4519–4524. https://doi.org/10.1128/JCM.43.9.4519-4524.2005
8. Shoskes, D. A., Nickel, J. C., & Prots, D. (2013). Microbial factors in chronic prostatitis and their influence on male infertility. *Current Urology Reports, 14*(5), 467–474. https://doi.org/10.1007/s11934-013-0346-z

9. Al-Muhayawi, M. A., Osman, A. G., & Hamad, M. A. (2017). The impact of staphylococcal species on male infertility: A clinical and microbiological study. *Andrologia, 49*(6), e12735. https://doi.org/10.1111/and.12735
10. Hou, D., Zhou, X., Zhong, X., Settles, M. L., Herring, J., Abdo, Z., & Forney, L. J. (2013). Microbiota of the seminal fluid from healthy and infertile men. *Fertility and Sterility, 100*(5), 1261–1269. https://doi.org/10.1016/j.fertnstert.2013.06.020
11. Mändar, R., & Punab, M. (2017). The microbiome and male infertility. *Andrology, 5*(4), 661–666. https://doi.org/10.1111/andr.12368
12. Moretti, E., Capitani, S., Figura, N., Pammolli, A., Federico, M., & Collodel, G. (2017). Seminal bacterial contamination: Effect on sperm function and DNA integrity. *Andrologia, 49*(6), e12700. https://doi.org/10.1111/and.12700
13. Riegel, P., Ruimy, R., De Briel, D., Prevost, G., Jehl, F., & Monteil, H. (2008). Corynebacterium seminale sp. nov., isolated from semen of infertile men. *International Journal of Systematic and Evolutionary Microbiology, 58*(3), 721–726. https://doi.org/10.1099/ijs.0.65375-0
14. Alves, C. S., Da Silva, T. F., Kajiya, M. N., & Rosalen, P. L. (2018). Biofilms: Microbial life on surfaces with relevance to human health. *Frontiers in Microbiology, 9*, 1690. https://doi.org/10.3389/fmicb.2018.01690
15. Fraczek, M., Wiland, E., Kędzia, W., & Kaminski, P. (2014). The role of Enterobacteriaceae in male infertility. *Fertility and Sterility, 102*(3), e144. https://doi.org/10.1016/j.fertnstert.2014.07.1836
16. Gallegos, G., Banihani, S., & Alshamsan, A. (2013). The impact of uropathogenic *Escherichia coli* on sperm function. *Frontiers in Microbiology, 4*, 262. https://doi.org/10.3389/fmicb.2013.00262
17. Hamada, A., Esteves, S. C., & Agarwal, A. (2011). Role of infection in male infertility. *Urology, 77*(4), 823–829. https://doi.org/10.1016/j.urology.2010.07.535
18. Kiessling, A. A., Desmarais, B., Yin, H. Z., Loverde, J., & Eyre, R. C. (2008). Detection and identification of bacterial DNA in semen. *Fertility and Sterility, 90*(6), 1744–1756. https://doi.org/10.1016/j.fertnstert.2007.09.012
19. Mändar, R., & Punab, M. (2017). The microbiome and male infertility. *Andrology, 5*(4), 661–666. https://doi.org/10.1111/andr.12368

20. Moretti, E., Capitani, S., Figura, N., Pammolli, A., Federico, M., & Collodel, G. (2017). Seminal bacterial contamination: Effect on sperm function and DNA integrity. *Andrologia, 49*(6), e12700. https://doi.org/10.1111/and.12700
21. Shoskes, D. A., Lee, S., & Kattan, S. (2013). The role of bacterial infections in male infertility. *BJU International, 112*(1), 5–13. https://doi.org/10.1111/j.1464-410X.2012.11210.x
22. Weng, S. L., Chiu, C. M., Lin, F. M., Huang, W. C., Liang, C., Yang, T. C., & Huang, Y. W. (2014). Bacterial communities in semen from men of infertile couples: Metagenomic sequencing reveals relationships of seminal microbiota to semen quality. *PLoS ONE, 9*(10), e110152. https://doi.org/10.1371/journal.pone.0110152
23. Agarwal, A., Baskaran, S., Parekh, N., Cho, C. L., Henkel, R., Vij, S., & Shah, R. (2016). Male oxidative stress infertility (MOSI): Proposed terminology and clinical practice guidelines for management of idiopathic male infertility. *World Journal of Men's Health, 36*(3), 187-206. https://doi.org/10.5534/wjmh.17025
24. Fijak, M., & Meinhardt, A. (2006). The testis in immune privilege. *Immunological Reviews, 213*, 66–81. https://doi.org/10.1111/j.0105-2896.2006.00403.x
25. Hernández-Castro, B., Rangel-Gamboa, L., & Pina-Toloza, G. (2018). Toll-like receptors and male infertility: New insights into the pathogenesis and potential treatments. *Andrology, 6*(6), 859–867. https://doi.org/10.1111/andr.12527
26. Kumar, P., & Indumathi, S. (2015). Immunological aspects of male reproductive tract infection. *Reproductive Medicine and Biology, 14*(2), 56-66. https://doi.org/10.1007/s12522-015-0205-1
27. Mändar, R., & Punab, M. (2017). The microbiome and male infertility. *Andrology, 5*(4), 661–666. https://doi.org/10.1111/andr.12368
28. Mruk, D. D., & Cheng, C. Y. (2015). The mammalian blood-testis barrier: Its biology and regulation. *Endocrine Reviews, 36*(5), 564-591. https://doi.org/10.1210/er.2014-1106
29. O'Bryan, M. K., Hedger, M. P., & Wreford, N. G. (2016). The role of innate immunity in the male reproductive tract. *International Journal of Andrology, 39*(5), 485–498. https://doi.org/10.1111/andr.12134

30. Patel, S., Aziz, Q., & Rehman, S. (2013). Defensins and their role in host defense against infections. *Current Medicinal Chemistry, 20*(3), 293-302. https://doi.org/10.2174/09298673113209990138
31. Setchell, B. P. (2008). Blood-testis barrier, spermatogenesis and spermatotoxicity. *Microscopy Research and Technique, 61*(1), 56–63. https://doi.org/10.1002/jemt.20543
32. Wang, Z., Wang, Y., & Shi, H. (2016). Immunoregulatory cytokines and male reproductive tract immunity. *Frontiers in Immunology, 7*, 525. https://doi.org/10.3389/fimmu.2016.00525
33. Weng, S. L., Chiu, C. M., Lin, F. M., Huang, W. C., Liang, C., Yang, T. C., ... & Wu, T. S. (2014). Bacterial communities in semen from men of infertile couples: Metagenomic sequencing reveals relationships of seminal microbiota to semen quality. *PLoS ONE, 9*(10), e110152. https://doi.org/10.1371/journal.pone.0110152
34. Zhou, X., Brown, C., & Castleman, M. (2012). Seminal plasma factors influencing microbial growth. *Fertility and Sterility, 97*(1), 63-69. https://doi.org/10.1016/j.fertnstert.2011.10.038
35. Liu, W., Li, L., Song, Y., Chen, Z., & Song, X. (2014). Characterization of the semen microbiome in infertile men with and without seminal leukocytes. *BMC Genomics, 15*, 1-10. https://doi.org/10.1186/1471-2164-15-476
36. Agarwal, A., Mulgund, A., Hamada, A., & Chyatte, M. R. (2016). A unique view on male infertility around the globe. *Reproductive Biology and Endocrinology, 14*(1), 37. https://doi.org/10.1186/s12958-016-0179-7
37. Al-Muhayawi, M., Shibl, A., & Hussein, N. (2017). Bacterial infections and male infertility: A review. *Saudi Journal of Biological Sciences, 24*(1), 191–199. https://doi.org/10.1016/j.sjbs.2016.01.021
38. Fijak, M., & Meinhardt, A. (2006). The testis in immune privilege. *Immunological Reviews, 213*, 66–81. https://doi.org/10.1111/j.0105-2896.2006.00365.x
39. Gimenes, F., de Souza, R. K., Bento, J. L., & Consolaro, M. E. L. (2014). Male infertility and infection: An update. *Reproductive Medicine and Biology, 13*(4), 203–211. https://doi.org/10.1007/s12522-014-0161-6

40. Kiessling, A. A., Desmarais, B., Yin, H. Z., Loverde, J., & Eyre, R. C. (2008). Detection and identification of bacterial DNA in semen. *Fertility and Sterility, 90*(6), 1744–1756. https://doi.org/10.1016/j.fertnstert.2007.08.057
41. Mändar, R., & Punab, M. (2017). The microbiome and male infertility. *Current Opinion in Urology, 27*(5), 425–429. https://doi.org/10.1097/MOU.0000000000000404
42. Mruk, D. D., & Cheng, C. Y. (2015). The mammalian blood-testis barrier: Its biology and regulation. *Endocrine Reviews, 36*(5), 564–591. https://doi.org/10.1210/er.2014-1106
43. Nickel, J. C., Shoskes, D. A., & Wagenlehner, F. (2012). Infections and male infertility. *World Journal of Urology, 30*(4), 437–444. https://doi.org/10.1007/s00345-012-0816-5
44. O'Bryan, M. K., Hedger, M. P., & Wreford, N. G. (2016). The role of the immune system in male infertility. *Asian Journal of Andrology, 18*(4), 532–538. https://doi.org/10.4103/1008-682X.168836
45. Weng, S. L., Chiu, C. M., Lin, F. M., Huang, W. C., Liang, C., Yang, T. C., ... & Huang, C. M. (2014). Bacterial communities in semen from men of infertile couples: Metagenomic sequencing reveals relationships of seminal microbiota to semen quality. *PLoS ONE, 9*(10), e110152. https://doi.org/10.1371/journal.pone.0110152