Review Article

VISCOELASTIC AND RHEOLOGICAL PROPERTIES OF SEMEN AND THEIR ROLE IN FERTILIZATION

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ABSTRACT

Semen is a complex biological fluid characterized by specific physicochemical properties. Among these, viscoelastic and rheological properties play a particularly important role, directly influencing sperm motility, transport through the female reproductive tract, and successful fertilization. The study of these properties is of great importance for both fundamental reproductive biology and clinical andrology and reproductive medicine.

Keywords: rheology properties, semen, viscoelasticity.

Introduction

Rheology is a cross-disciplinary field that studies the flow and deformation of matter. At the beginning of the last century, rheology was mainly related to physics and analytical chemistry; however, today rheological research has become an important area of both fundamental and applied biomedicine. All biological fluids, including semen, are non-Newtonian. Their viscosity varies with the deformation rate and external conditions. The main rheological characteristics of semen include: viscosity, elasticity, fluidity, liquefaction time, thixotropy, and shear resistance.

Materials and Methods

We analyzed contemporary literature available in PubMed using filters for the years 2022-2026 and the keywords “viscoelastic properties of human semen” and “rheological properties of human semen”. The keywords included both phrases and individual terms. Based on the analysis of the selected articles, the main concepts were systematized and integrated into the fundamental framework of the presented results.

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Results

Semen Viscosity

Viscosity is the ability of a fluid to resist flow. Normal semen after ejaculation has a relatively thick consistency; however, within 15-60 minutes it undergoes liquefaction under the action of prostatic enzymes. Increased semen viscosity is referred to as hyperviscosity and may lead to decreased sperm motility, impaired penetration through cervical mucus, and reduced probability of natural fertilization.[1]

Elasticity

Elasticity characterizes the ability of semen to restore its shape after mechanical stress. It is determined by interactions between seminal plasma proteins, mucins, and other macromolecules. Excessive elasticity may hinder free sperm movement, whereas moderate viscoelastic properties help retain the ejaculate within the female reproductive tract.[2]

Composition of Semen and Formation of Its Rheological Properties

Semen consists of: spermatozoa; seminal vesicle secretions; prostatic secretions; seminal plasma proteins; semen lipids; semen enzymes; ions and water.Seminal plasma proteins form the structural basis of semen and participate in the regulation of sperm function. These mainly include: structural proteins responsible for temporary semen coagulation after ejaculation; transport proteins that bind and transport ions, hormones, lipids, and trace elements; enzymatic proteins involved in catalytic functions and in semen liquefaction; and immune proteins that protect spermatozoa from immune reactions and microorganisms. Important seminal proteins include: semenogelins, albumins, globulins, fibronectin, and lactoferrin. Lipids are components of sperm membranes and seminal plasma. They are essential for maintaining cellular structure and energy metabolism. Major semen lipids include: phospholipids, which form sperm membranes; cholesterol, which regulates membrane fluidity and participates in capacitation; fatty acids, serving as energy sources and membrane components; and sphingolipids involved in cell signaling. Semen enzymes play an important role in sperm viability, semen liquefaction, and fertilization. Most enzymes originate from the prostate gland and seminal vesicles. The major enzymes include: prostate-specific antigen (PSA), responsible for semen liquefaction after ejaculation through degradation of coagulum proteins; hyaluronidase, which helps sperm penetrate the oocyte coverings by degrading hyaluronic acid; acrosin, a proteolytic enzyme involved in zona pellucida penetration; and acid phosphatase, a marker of prostatic secretion.[3,4]

Table 1. Main Factors Affecting Semen Rheology.

Factor	Influence
Seminal plasma proteins	Form gel-like structures
Fibrinogen-like substances	Provide coagulation after ejaculation.
Prostatic enzymes	Cause semen liquefaction
Environmental pH	Alters motility and viscosity
Cell concentration	Influences flow resistance

Mechanism of Changes in Semen Viscosity After Ejaculation

After ejaculation, semen undergoes two sequential stages: coagulation and liquefaction. Immediately after ejaculation, semen becomes thicker. This contributes to: retention of semen in the vagina; protection of spermatozoa from the acidic environment; reduction of seminal fluid loss. Proteins secreted by the seminal vesicles mediate coagulation. Within 15-60 minutes, under the influence of prostate-specific antigen (PSA), protein structures are degraded, and semen becomes more fluid. Liquefaction is necessary for: activation of sperm motility; penetration through cervical mucus; migration toward the oocyte.[3,5]

Role of Rheological Properties in Fertilization

The role of rheological properties in fertilization is extensive, although modern scientific literature contains relatively few studies specifically focused on semen rheology. Semen rheology influences sperm motility. Spermatozoa move within a complex viscoelastic environment, and their flagella must overcome fluid resistance. Optimal viscosity ensures effective sperm progression, reduced energy expenditure, and protection from mechanical damage. Excessive viscosity decreases sperm velocity and reduces the likelihood of reaching the oocyte.[2,3,6]

Penetration Through Cervical Mucus

Cervical mucus itself possesses pronounced rheological properties. Successful sperm penetration requires appropriate compatibility between semen viscosity, cervical mucus structure, and flagellar activity. Disruption of these interactions may reduce the probability of fertilization. Modern studies demonstrate that in viscous environments spermatozoa can generate collective movements and microflows that enhance migration efficiency. Such hydrodynamic interactions are especially important within the fallopian tubes.[5,6]

Pathological Changes

On one hand, Semen hyperviscosity, considered a pathological marker, may develop due to: inflammatory diseases; genital tract infections; oxidative stress; impaired prostate function; increased leukocyte concentration. On the other hand, impaired liquefaction associated with insufficient activity of prostatic enzymes results in persistently thick semen. This condition may be caused by: chronic prostatitis**,** hormonal disorders, zinc deficiency, and prostate diseases.[6]

Methods for Studying Semen Rheology

The investigation of semen rheology combines laboratory and high-technology methods, including viscometry, rheometry, microscopy, liquefaction time analysis, and computer-assisted sperm analysis (CASA). These investigations help diagnose male infertility, assess treatment efficacy, select assisted reproductive technologies (IVF, ICSI), and predict the probability of natural conception.[7]

Conclusion

Viscoelastic and rheological properties of semen play a crucial role in the reproductive process. They determine the efficiency of sperm transport, the ability of spermatozoa to overcome barriers within the female reproductive tract, and ultimately to reach and fertilize the oocyte. Alterations in these properties may significantly reduce male fertility and represent one of the causes of infertility. Modern diagnostic methods allow detailed investigation of

semen rheological characteristics and enable the use of these findings to optimize treatment and assisted reproductive technologies. The study of semen as a complex biophysical system remains an important and promising area of modern medicine and biophysics.

Declarations

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Conflict of Interest: The authors declare no competing interests.

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