Antibacterial Mechanisms of *Swarnaprashana*: Integrating in-Vitro Evidence with Ayurvedic and Modern Scientific Perspectives

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Abstract

Infectious diseases remain a major cause of morbidity among children because of their immature immune system, while the rapid emergence of antimicrobial resistance (AMR) has reduced the effectiveness of conventional antibiotics. *Swarnaprashana,* a classical Ayurvedic formulation composed of *Swarna Bhasma, Madhu,* and *Ghrita,* has traditionally been used to enhance immunity and disease resistance in children. Although recent in vitro studies have demonstrated its antibacterial activity, the underlying mechanisms have not been comprehensively explained. To critically review and integrate the available scientific evidence on the antimicrobial mechanisms of *Swarnaprashana* by correlating published in vitro findings with contemporary microbiological knowledge and classical Ayurvedic concepts. A narrative literature review was conducted by analysing published in vitro studies on *Swarnaprashana* and its major constituents, including *Swarna Bhasma, Madhu,* and *Ghrita*. Evidence from microbiology, nanomedicine, pharmacology, and classical Ayurvedic literature was synthesized to explain the possible mechanisms responsible for the observed antibacterial activity. The available evidence suggests that *Swarnaprashana* exerts antibacterial activity through multiple complementary mechanisms. *Swarna Bhasma* may disrupt bacterial cell membranes, generate reactive oxygen species, inhibit metabolic enzymes, and interfere with DNA replication and protein synthesis. *Madhu* contributes through its high osmotic pressure, acidic pH, hydrogen peroxide production, phenolic compounds, and inhibition of biofilm formation. *Ghrita* primarily functions as a bio-enhancing lipid carrier that improves the stability, dispersion, and delivery of active constituents while also providing antioxidants and immunomodulatory support. The combined action of these components may produce a synergistic antibacterial effect against both Gram-positive and Gram-negative bacteria. Current evidence supports the potential antibacterial activity of *Swarnaprashana* and provides a scientific basis for its traditional use in pediatric healthcare. Nevertheless, the evidence is largely limited to in vitro studies. Further molecular investigations, standardized experimental studies, and well-designed clinical trials are required to validate its mechanisms, establish safety, and determine its therapeutic role in infection prevention and antimicrobial resistance management.

Keywords: *Swarnaprashana;* Antibacterial mechanisms; Gold nanoparticles; *Madhu; Ghrita;* Pediatric immunity; Antimicrobial resistance.

Introduction

Children, particularly neonates and young children, are highly susceptible to infectious diseases because of the immaturity of their immune system [1]. Diarrhoea, pneumonia, and infectious diseases are more prevalent in India, particularly among children [2]. Bacterial pathogens such as *Escherichia coli* and *Staphylococcus aureus* are frequently associated with infections ranging from gastrointestinal and urinary tract infections to severe systemic infections. Therefore, the identification of safe, effective, and traditionally acceptable agents with antibacterial potential is of considerable importance in pediatric healthcare [3].

Antimicrobial resistance (AMR) has become a major global public-health concern, substantially reducing the effectiveness of established antibacterial therapies and increasing the need for the discovery of novel antimicrobial agents and alternative therapeutic strategies [4]. The increasing prevalence of resistant bacterial pathogens has stimulated scientific investigation into naturally derived substances and traditional medicinal preparations as potential sources of antimicrobial compounds [5]. In this context, traditional medical systems such as Ayurveda provide a valuable source of multi-component formulations that may contain several biologically active constituents capable of exerting complementary or synergistic biological effects [6].

Ayurveda emphasizes preventive healthcare through the promotion of *Vyadhikshamatva* (disease resistance), *Bala* (strength), and *Rasayana* (rejuvenation). Among the various pediatric interventions described in the classical texts, *Swarnaprashana* is regarded as a unique formulation recommended by Acharya Kashyapa for promoting physical growth, cognitive development, immunity, and overall well-being. Traditionally, *Swarnaprashana* consists of *Swarna Bhasma* (incinerated gold), *Madhu* (honey), and *Ghrita* (ghee) administered in appropriate doses to

children. Classical Ayurvedic literature attributes to this formulation properties such as *Medhya* (intellect-promoting), *Balya* (strengthening), *Ayushya* (life-promoting), *Vrishya*, and *Vyadhikshamatva*-enhancing, suggesting its potential role in protecting children from recurrent illnesses [7].

Swarna Bhasma is a processed gold preparation that may contain fine or nano-sized gold particles, depending on its method of preparation. Experimental studies have suggested that gold-based nanoparticles may exhibit antibacterial activity through mechanisms such as interaction with the bacterial cell envelope, disruption of membrane integrity, oxidative stress, and interference with essential cellular processes. Thus, the physicochemical characteristics of *Swarna Bhasma* may contribute to the antibacterial potential of *Swarnaprashana* [8,9].

Madhu is a naturally occurring antimicrobial substance with a well-established history of therapeutic use. Its antibacterial activity is associated with multiple mechanisms, including high osmotic pressure, low pH, hydrogen peroxide generation, and the presence of phenolic compounds and other bioactive constituents. These mechanisms may inhibit bacterial growth and contribute to the activity of the overall *Swarnaprashana* formulation [10].

Similarly, *Ghrita* is traditionally regarded as a *Yogavahi* and bio-enhancing substance that may facilitate the delivery and assimilation of other components. Its lipid constituents, including short-chain fatty acids and other bioactive compounds, may possess antimicrobial properties and may contribute to the antibacterial activity of the formulation. The combined presence of *Swarna Bhasma, Madhu*, and *Ghrita* may therefore produce a complementary or synergistic antibacterial effect through multiple mechanisms [11,12].

Emerging in vitro studies have reported antibacterial activity of *Swarnaprashana* against both Gram-positive and Gram-negative bacteria, supporting the traditional belief that the formulation contributes to resistance against infectious diseases. However, most available investigations primarily describe antimicrobial activity without comprehensively explaining the biological mechanisms responsible for these observations. Furthermore, the existing evidence remains fragmented across studies focusing separately on *Swarna Bhasma, Madhu, Ghrita,* nanotechnology, or Ayurvedic principles, highlighting the need for an integrated scientific interpretation.

Therefore, the present review aims to provide an evidence-based analysis of the antimicrobial mechanisms of *Swarnaprashana* by integrating published in vitro findings with contemporary microbiological evidence and classical Ayurvedic concepts. Rather than presenting new experimental data, this review critically examines the available literature to explain the possible mechanisms through which *Swarnaprashana* may inhibit microbial growth, including disruption of bacterial cell membranes, oxidative stress induction, interference with microbial metabolism, biofilm inhibition, and immunomodulatory effects. By bridging traditional Ayurvedic knowledge with modern scientific understanding, this review seeks to provide a comprehensive framework for future experimental and clinical research on *Swarnaprashana* as a potential adjunct in infection prevention and pediatric healthcare.

AIM & OBJECTIVES

Aim: -

- To critically review and integrate the available scientific and Ayurvedic evidence regarding the antimicrobial mechanisms of *Swarnaprashana*, with emphasis on published in vitro findings and their relevance to modern microbiological concepts and pediatric healthcare.

Objectives: -

- To review the classical Ayurvedic concepts underlying the use of *Swarnaprashana* in promoting immunity and disease resistance.
- To summarize the scientific evidence available on the antimicrobial activity of *Swarnaprashana* and its individual components (*Swarna Bhasma, Madhu*, and *Ghrita*).
- To explain the possible antimicrobial mechanisms of *Swarnaprashana* based on contemporary microbiological and nanomedicine research.
- To integrate published in vitro findings with Ayurvedic principles and modern scientific evidence.

EVIDENCE FROM PUBLISHED IN VITRO STUDIES

Swarnaprashana has traditionally been used in Ayurveda as a *Rasayana* formulation to promote immunity and disease resistance in children. However, scientific evidence regarding its direct antibacterial activity has remained limited. A recently published in vitro study conducted by the present authors demonstrated that *Swarnaprashana* possesses concentration-dependent antibacterial activity against both Staphylococcus aureus and Escherichia coli using the well diffusion method. Higher concentrations produced greater antibacterial activity, while Staphylococcus aureus showed greater susceptibility than Escherichia coli. In addition, *Swarnaprashana* prepared with dimethyl sulfoxide (DMSO) exhibited enhanced antibacterial activity, suggesting improved dispersion and diffusion of the active constituents [13].

These findings provide experimental evidence supporting the antibacterial potential of *Swarnaprashana.* However, the previously published study primarily focused on evaluating antibacterial activity and did not comprehensively explain the molecular and cellular mechanisms responsible for these effects. Therefore, the present article extends those findings by integrating available evidence on the antibacterial mechanisms of *Swarna Bhasma, Madhu*, and *Ghrita* with classical Ayurvedic concepts and contemporary microbiological research. This mechanistic approach provides a broader scientific understanding of how the individual components of *Swarnaprashana* may contribute to its overall antibacterial activity.

DISCUSSION

Antimicrobial Mechanisms of *Swarnabhasma*

Swarna Bhasma is a traditional Ayurvedic herbo-mineral preparation produced through the sequential processes of *Shodhana* (purification) and *Marana* (incineration) of gold. Recent advances in nanotechnology have demonstrated that properly prepared Swarna Bhasma contains nano- to submicron-sized gold particles with unique physicochemical properties, including a high surface-area-to-volume ratio, enhanced surface reactivity, and improved biological interaction. These characteristics enable intimate contact between the gold particles and microbial cells, thereby contributing to their antimicrobial activity. In this present research, the antibacterial potential of *Swarnaprashana* against Staphylococcus aureus and Escherichia coli could be attributed, to some extent, to the presence of *Swarnabhasma.*

The antimicrobial action of *Swarna Bhasma* may occur through several mechanisms:

- Initial Interaction with the Bacterial Cell Surface.
- Membrane Damage and Loss of Cellular Integrity.
- Generation of Reactive Oxygen Species (ROS).
- Inhibition of Essential Metabolic Enzymes.
- Interference with DNA Replication and Protein Synthesis.
- Role of Nanoparticle Characteristics.
- Multifactorial Antibacterial Mechanism.

1. Initial Interaction with the Bacterial Cell Surface

The antimicrobial process begins with the adsorption of nano-sized gold particles onto the bacterial cell surface. Because bacterial cell walls possess a negative net surface charge, electrostatic attraction facilitates the attachment of gold particles to the cell envelope. This close interaction alters the structural organization of the cell wall and cytoplasmic membrane, leading to increased membrane permeability. As membrane integrity is progressively compromised, essential intracellular constituents, including potassium ions, proteins, nucleic acids, and other metabolites, leak into the extracellular environment. The resulting loss of cellular homeostasis adversely affects bacterial survival.

2. Membrane Damage and Loss of Cellular Integrity-

Following surface attachment, gold nanoparticles further destabilize the bacterial membrane by disturbing its lipid bilayer and membrane-associated proteins. This structural disruption interferes with the membrane's selective permeability, causing uncontrolled movement of ions and water across the membrane. Such alterations impair nutrient transport, waste removal, and maintenance of osmotic balance, eventually resulting in irreversible membrane damage and bacterial cell lysis.

3. Generation of Reactive Oxygen Species (ROS)-

Another important mechanism involves the intracellular generation of reactive oxygen species (ROS), including superoxide anions, hydroxyl radicals, and hydrogen peroxide. Excessive ROS production exceeds the antioxidant defense capacity of bacterial cells, producing severe oxidative stress. Oxidative stress causes lipid peroxidation of the cell membrane, oxidation of structural and enzymatic proteins, and fragmentation of bacterial DNA. These cumulative injuries disrupt normal cellular physiology and significantly reduce bacterial viability.

4. Inhibition of Essential Metabolic Enzymes-

Gold nanoparticles may also interact with sulfhydryl (-SH) groups present in several bacterial enzymes. This interaction inhibits enzymes involved in the electron transport chain, ATP synthesis, cellular respiration, and other metabolic pathways. Consequently, bacterial cells experience reduced energy production and impaired metabolic activity, limiting their ability to grow, divide, and survive.

5. Interference with DNA Replication and Protein Synthesis-

After penetrating the bacterial cell, gold particles may interfere with nucleic acid metabolism by inducing oxidative DNA damage and inhibiting DNA replication. Simultaneously, interaction with ribosomal proteins may disrupt protein synthesis by preventing the formation of essential structural and functional proteins. These effects collectively inhibit bacterial multiplication and contribute to both bacteriostatic and bactericidal activity.

6. Role of Nanoparticle Characteristics-

The antimicrobial efficacy of *Swarna Bhasma* is strongly influenced by its nanoparticle characteristics. The extremely small particle size provides a large surface-area-to-volume ratio, enabling greater interaction with bacterial cells and facilitating intracellular penetration. The increased surface reactivity enhances the ability of gold particles to interfere with multiple cellular targets simultaneously, thereby improving overall antibacterial effectiveness.

7. Multifactorial Antibacterial Mechanism-

Unlike conventional antibiotics, which usually inhibit a single bacterial target, *Swarna Bhasma* appears to exert its antibacterial activity through multiple complementary mechanisms operating simultaneously. These include disruption of membrane integrity, induction of oxidative stress, inhibition of metabolic enzymes, suppression of ATP generation, impairment of DNA replication, and inhibition of protein synthesis. Because several vital cellular

pathways are affected concurrently, bacterial adaptation and the development of resistance may be less likely compared with single-target antimicrobial agents.

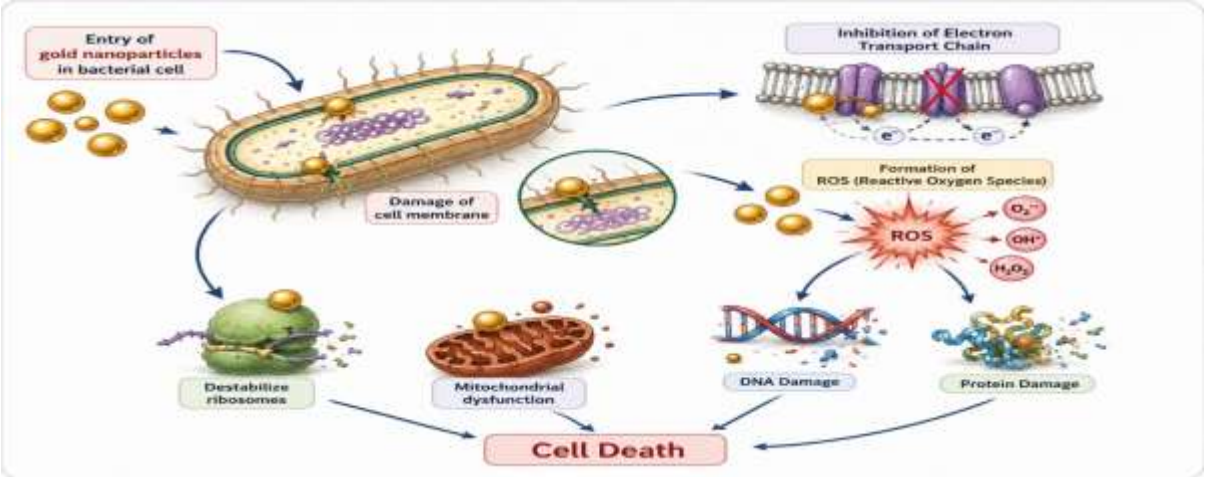

Figure 01: Antibacterial Mechanisms Of Gold Nanoparticles (*Swarnabhasma)*

Ayurveda classifies *Swarnabhasma* as *Krimighna, Ojovardhaka*, and *Rasayana*. This means that *Swarnabhasma* is connected to its ability to stop the growth of microbes and boost the body's defences. So, *Swarnabhasma* is an important part that helps make *Swarnaprashana* work as an antimicrobial[14].

ANTIMICROBIAL MECHANISMS OF *MADHU*

Madhu (honey) is a natural biological product that has been used in traditional medicine for centuries because of its wound-healing, antimicrobial, anti-inflammatory, and antioxidant properties. Honey possesses well-established antimicrobial properties and acts as both a therapeutic agent and a carrier substance in *Swarnaprashana.*

Its antimicrobial activity is attributed to:

- High osmolarity causes dehydration of microbial cells.
- Acidic ph unfavorable for bacterial growth.
- Enzymatic production of hydrogen peroxide.
- Presence of flavonoids, phenols, and antioxidant compounds.
- Disruption of Bacterial Cell Membrane.
- Inhibition of Biofilm Formation.
- Interference with Bacterial Metabolism.
- Synergistic Antimicrobial Action.

1. High Osmotic Pressure-

One of the primary mechanisms responsible for the antimicrobial activity of honey is its high osmotic effect. Honey contains approximately 80–85% sugars, mainly fructose and glucose, with relatively low water content. This creates a hyperosmotic environment that draws water out of bacterial cells by osmosis, leading to cellular dehydration, plasmolysis, and inhibition of microbial growth. The reduction in water activity also limits bacterial metabolism and prevents multiplication.

2. Acidic pH-

Honey possesses a naturally acidic pH, generally ranging between 3.2 and 4.5. Most pathogenic bacteria, including Escherichia coli and Staphylococcus aureus, grow optimally at a near-neutral pH. The acidic environment created by honey interferes with bacterial enzyme activity, nutrient transport, and cellular metabolism, thereby suppressing bacterial proliferation and survival.

3. Production of Hydrogen Peroxide-

A major contributor to the antimicrobial activity of honey is the enzymatic generation of hydrogen peroxide. Honey contains the enzyme glucose oxidase, which becomes active when honey is diluted with moisture or biological fluids. This enzyme converts glucose into gluconic acid and hydrogen peroxide. The slow and continuous release of low concentrations of hydrogen peroxide produces sustained antimicrobial activity while minimizing damage to surrounding tissues. Hydrogen peroxide induces oxidative stress by damaging bacterial cell membranes, proteins, and nucleic acids, ultimately resulting in bacterial cell death.

4. Presence of Phytochemicals and Phenolic Compounds

Honey contains numerous bioactive phytochemicals, including flavonoids, phenolic acids, tannins, and other antioxidant compounds. These molecules exhibit direct antimicrobial activity by disrupting bacterial cell membranes, inhibiting essential metabolic enzymes, and interfering with nucleic acid synthesis. In addition, their antioxidant properties help regulate oxidative balance and contribute to tissue protection during infection.

5. Disruption of Bacterial Cell Membrane
Several constituents of honey interact directly with the bacterial cell envelope, increasing membrane permeability and altering membrane integrity. This results in leakage of intracellular components such as potassium ions, proteins, and nucleic acids, leading to loss of cellular homeostasis and eventual bacterial death.

6. Inhibition of Biofilm Formation
Many pathogenic bacteria produce biofilms that protect them from antimicrobial agents and host immune responses. Honey has been shown to inhibit bacterial adhesion, interfere with quorum sensing, and disrupt biofilm formation. As a result, bacteria become more susceptible to antimicrobial action and are less capable of establishing persistent infections.

7. Interference with Bacterial Metabolism
Honey inhibits several metabolic pathways essential for bacterial survival. It reduces cellular respiration, interferes with ATP production, and suppresses protein synthesis by affecting key metabolic enzymes. These effects decrease bacterial growth and replication, contributing to its broad-spectrum antibacterial activity.

8. Synergistic Antimicrobial Action
The antimicrobial efficacy of honey is not attributable to a single constituent but rather to the synergistic interaction of its high osmolarity, acidic pH, hydrogen peroxide production, phenolic compounds, flavonoids, antimicrobial peptides, and other naturally occurring bioactive molecules. This multifactorial mechanism acts simultaneously on multiple bacterial targets, making the development of microbial resistance comparatively less likely than with conventional antibiotics.
These factors inhibit the growth of various pathogenic microorganisms, including Staphylococcus aureus, Escherichia coli, and Pseudomonas aeruginosa. Honey also prevents biofilm formation and promotes wound healing by reducing microbial colonization.

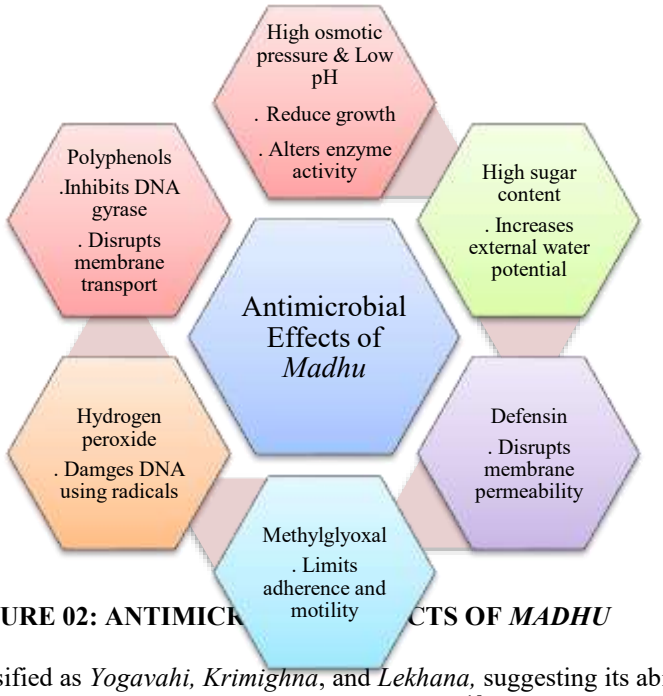

FIGURE 02: ANTIMICR CTS OF *MADHU*

Ayurvedically, *Madhu* is classified as *Yogavahi, Krimighna*, and *Lekhana,* suggesting its ability to potentiate the action of associated drugs while manifesting its own antimicrobial effects[15].

ANTIMICROBIAL MECHANISMS OF *GHRITA*
Ghrita (clarified butter) is a major lipid carrier in *Swarnaprashana* and has a supportive but crucial role in antimicrobial action. Although *Ghrita* alone may not possess potent direct antibacterial activity in vitro, its role as a lipid carrier is of prime importance in enhancing the stability, dispersion, and penetration of the active principles, such as *Swarnabhasma* and phytoconstituents.

lipid-rich composition facilitates:
- Presence of Bioactive Fatty Acids.
- Disruption of Bacterial Cell Membrane.
- Antioxidant Activity and Cellular Protection.
- Immunomodulatory Effect.
- Enhancement of Drug Delivery (*Yogavahi* Property).
- Maintenance of Microbial Homeostasis.
- Synergistic Role in Polyherbal and Herbo-mineral Formulations.

1. Presence of Bioactive Fatty Acids
Ghrita contains several biologically active fatty acids, including butyric acid, palmitic acid, stearic acid, oleic acid, and conjugated linoleic acid (CLA). Certain fatty acids exhibit antimicrobial activity by interacting with bacterial cell membranes. Their lipophilic nature allows them to penetrate the phospholipid bilayer, disturbing membrane organization, increasing membrane permeability, and causing leakage of intracellular constituents. These changes impair bacterial survival and inhibit microbial growth.

2. Disruption of Bacterial Cell Membrane
The lipid components of *Ghrita* may integrate into the bacterial membrane and alter its structural integrity. This interaction disturbs membrane fluidity, affects transmembrane transport, and compromises selective permeability. As a result, bacterial cells lose essential ions, proteins, and metabolites required for normal cellular function. The disruption of membrane homeostasis ultimately reduces bacterial viability.

3. Antioxidant Activity and Cellular Protection
Ghrita is naturally rich in lipid-soluble antioxidants such as vitamins A, D, E, K, carotenoids, and other antioxidant molecules. These compounds protect host tissues from oxidative damage generated during infection and inflammation. Although antioxidant activity does not directly kill bacteria, it minimizes tissue injury, preserves cellular integrity, and creates a physiological environment that supports effective host defense mechanisms.

4. Immunomodulatory Effect-
One of the important biological properties of *Ghrita* is its immunomodulatory activity. Experimental studies indicate that *Ghrita* may enhance both innate and adaptive immune responses by improving macrophage function, promoting phagocytosis, and regulating cytokine production. Enhanced immune activity facilitates more efficient recognition, engulfment, and elimination of invading microorganisms, thereby contributing indirectly to antimicrobial defense.

5. Enhancement of Drug Delivery *(Yogavahi* Property)
According to Ayurvedic principles, *Ghrita* acts as a *Yogavahi*, meaning it enhances the delivery and therapeutic efficacy of co-administered substances without altering their intrinsic properties. Owing to its lipid-rich composition, *Ghrita* improves the dispersion, stability, and bioavailability of lipophilic phytochemicals and mineral preparations such as *Swarna Bhasma*. This carrier function facilitates better interaction of active constituents with microbial cells and may potentiate the overall antimicrobial activity of the formulation.

6. Maintenance of Microbial Homeostasis-
Butyric acid, a short-chain fatty acid naturally present in *Ghrita*, has been shown to support intestinal epithelial health, maintain mucosal integrity, and regulate local immune responses. By strengthening the intestinal barrier and promoting beneficial microbiota, *Ghrita* may indirectly reduce the colonization and proliferation of pathogenic microorganisms, thereby contributing to microbial homeostasis.

7. Synergistic Role in Polyherbal and Herbo-mineral Formulations
Ghrita is frequently used as a lipid vehicle in Ayurvedic formulations because of its ability to enhance the stability and therapeutic performance of active ingredients. In formulations such as *Swarnaprashana, Ghrita* acts synergistically with *Madhu* and *Swarna Bhasma* by improving the uniform distribution and sustained release of active constituents. This synergistic interaction enhances the overall antimicrobial potential of the formulation, even though *Ghrita* alone exhibits relatively mild antibacterial activity.

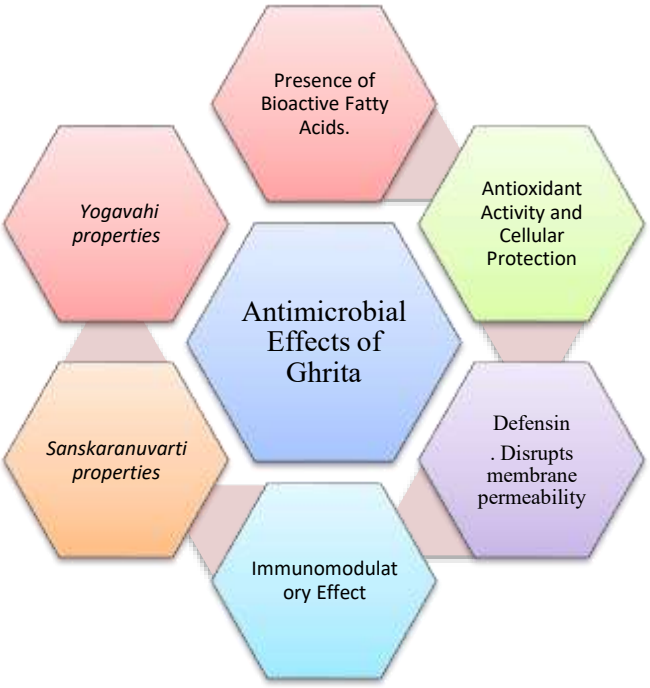

Figure 03: Antimicrobial Effects Of *Ghrita*

From an Ayurvedic standpoint, *Ghrita* is characterised as *Sanskaranuvarti, Yogavahi*, and *Balya,* which highlights its capacity to carry and improve the therapeutic properties of drugs when processed with it. In this case, *Ghrita* is not entirely a primary antimicrobial substance but functions as a critical adjuvant that optimises the antimicrobial efficacy of formulation [16].

SYNERGISTIC ANTIBACTERIAL MECHANISMS OF *SWARNAPRASHANA* FORMULATION

The antibacterial activity of *Swarnaprashana* is likely attributable to the synergistic interaction of its three principal constituents—*Swarna Bhasma, Madhu*, and *Ghrita*—rather than to the action of any single ingredient alone. *Swarna Bhasma* contributes through nanoparticle-mediated disruption of bacterial cell membranes, induction of oxidative stress, inhibition of metabolic enzymes, and interference with nucleic acid and protein synthesis. *Madhu* provides complementary antimicrobial effects through its high osmotic pressure, acidic pH, continuous production of hydrogen peroxide, phenolic compounds, and inhibition of bacterial biofilm formation. *Ghrita* functions primarily as a lipid-based carrier (*Yogavahi*), enhancing the stability, dispersion, absorption, and bioavailability of the active constituents while contributing supportive immunomodulatory and antioxidant effects.

The integration of these diverse mechanisms enables *Swarnaprashana* to target multiple bacterial structures and metabolic pathways simultaneously. Such a multifactorial mode of action may enhance overall antibacterial efficacy and potentially reduce the likelihood of bacterial adaptation compared with agents acting through a single molecular target. This synergistic interaction represents one of the major scientific rationales underlying the traditional Ayurvedic use of *Swarnaprashana* as a pediatric *Rasayana* and supports further mechanistic and translational research.

AYURVEDIC INTERPRETATION OF ANTIBACTERIAL ACTIVITY

The antibacterial activity demonstrated by *Swarnaprashana* in published in vitro studies can be interpreted through the fundamental Ayurvedic concepts of *Krimighna Karma, Vyadhikshamatva*, *Rasayana,* and *Ojas*. Although classical Ayurvedic literature does not describe microorganisms in the terminology of modern microbiology, the concept of *Krimi* broadly encompasses disease-causing organisms responsible for various infectious conditions. Therefore, the inhibition of microbial growth observed experimentally may be correlated with the *Krimighna* (antimicrobial) action described in Ayurveda [16-18].

From an Ayurvedic perspective, the therapeutic significance of *Swarnaprashana* extends beyond direct antimicrobial activity. Ayurveda emphasizes enhancement of the host's resistance to disease rather than merely eliminating pathogens. Thus, the antibacterial effects observed against Staphylococcus aureus and Escherichia coli may be considered one component of its broader action in promoting *Vyadhikshamatva* (disease resistance). The classical concept of *Rasayana* further suggests improvement in tissue nourishment, maintenance of Ojas, and strengthening of natural defence mechanisms, thereby reducing susceptibility to recurrent infections [16-18].

The multifactorial antibacterial mechanisms identified in contemporary research—including bacterial membrane disruption, oxidative stress induction, inhibition of essential metabolic pathways, and prevention of biofilm formation—may collectively be interpreted as the modern scientific expression of *Krimighna Karma*. Simultaneously, the immunomodulatory effects reported for *Swarnaprashana* are consistent with the Ayurvedic concepts of *Balya*, *Ojovardhana*, and enhancement of *Vyadhikshamatva* [13-16].

Therefore, the available evidence supports an integrated interpretation in which the antibacterial activity of *Swarnaprashana* reflects both direct inhibition of pathogenic microorganisms and strengthening of host defence mechanisms. This correlation between classical Ayurvedic principles and contemporary microbiological evidence provides a rational scientific basis for its traditional use in pediatric healthcare and warrants further experimental and clinical investigation [16-18].

ROLE OF SWARNAPRASHANA IN COMBATING ANTIMICROBIAL RESISTANCE

Antimicrobial resistance (AMR) has emerged as one of the greatest global public health challenges, resulting in reduced efficacy of conventional antibiotics and increasing morbidity, mortality, and healthcare costs. The widespread and inappropriate use of antimicrobial agents has accelerated the emergence of multidrug-resistant (MDR) bacterial strains, emphasizing the urgent need for alternative or adjunctive therapeutic approaches.

Unlike conventional antibiotics, which generally target a single bacterial pathway, *Swarnaprashana* appears to exert antibacterial activity through multiple complementary mechanisms. Available evidence suggests that its constituents collectively disrupt bacterial cell membranes, induce oxidative stress, inhibit essential metabolic enzymes, interfere with DNA replication and protein synthesis, and suppress biofilm formation. Simultaneous interference with multiple cellular targets may reduce the likelihood of rapid development of bacterial resistance, although this hypothesis requires further experimental confirmation.

In addition to its direct antibacterial effects, *Swarnaprashana* possesses immunomodulatory properties that may enhance host defence mechanisms. From an Ayurvedic perspective, this corresponds to enhancement of *Vyadhikshamatva*, enabling the host to resist microbial infections more effectively. Therefore, rather than functioning solely as an antimicrobial agent, *Swarnaprashana* may serve as an adjunctive therapeutic strategy by simultaneously reducing bacterial burden and improving host immunity.

Although current evidence remains predominantly limited to in vitro investigations, the multifactorial mechanism of *Swarnaprashana* highlights its potential relevance in future antimicrobial research. Further molecular studies and well-designed clinical trials are necessary to determine whether this traditional formulation can contribute to combating antimicrobial resistance in clinical practice.

CLINICAL IMPLICATIONS IN PEDIATRIC HEALTHCARE

The findings summarized in this review suggest that *Swarnaprashana* may have potential clinical relevance in pediatric healthcare because of its combined antibacterial, immunomodulatory, and *Rasayana* properties. Children are particularly vulnerable to recurrent bacterial infections owing to the immaturity of their immune system. Therefore, interventions that support both host immunity and antimicrobial defence are of considerable interest.

The available in vitro evidence indicates that *Swarnaprashana* possesses antibacterial activity against clinically important pathogens such as Staphylococcus aureus and Escherichia coli. However, these findings should not be interpreted as evidence that *Swarnaprashana* can replace conventional antibiotic therapy. Instead, it may be considered a complementary formulation that supports immune function and may contribute to infection prevention when administered according to classical Ayurvedic principles.

Future clinical studies should evaluate its effectiveness in reducing the frequency of recurrent infections, improving immune biomarkers, enhancing vaccine responsiveness, and decreasing antibiotic consumption in children. Such evidence will be essential before routine clinical recommendations can be made.

Conclusion

Swarnaprashana is a classical Ayurvedic formulation that has traditionally been used to promote immunity, healthy growth, and resistance to diseases in children. The available scientific evidence, although still limited, indicates that it also possesses measurable antibacterial activity against both Gram-positive and Gram-negative bacteria. This review integrates published in vitro findings with contemporary microbiological knowledge and Ayurvedic principles to explain the possible mechanisms responsible for these effects.

The antibacterial activity of *Swarnaprashana* appears to result from the complementary actions of its three principal components. *Swarna Bhasma* may exert antimicrobial effects through disruption of the bacterial cell membrane, induction of oxidative stress, inhibition of essential metabolic enzymes, and interference with DNA replication and protein synthesis. *Madhu* contributes through its high osmolarity, acidic pH, enzymatic production of hydrogen peroxide, and the presence of phenolic compounds that collectively inhibit bacterial growth and biofilm formation. *Ghrita*, although not a potent antibacterial agent by itself, serves as an effective lipid carrier that enhances the stability, bioavailability, and delivery of the active constituents while providing additional antioxidants and immunomodulatory benefits.

Unlike conventional antibiotics that usually target a single bacterial pathway, *Swarnaprashana* may act through multiple complementary mechanisms simultaneously. Such a multifactorial mode of action may reduce the likelihood of bacterial resistance and supports the traditional Ayurvedic concept of improving *Vyadhikshamatva* (disease resistance) rather than merely eliminating pathogens.

Overall, the available evidence suggests that *Swarnaprashana* has promising antibacterial potential and provides a scientific basis for its traditional use in pediatric healthcare. However, the current evidence is largely derived from experimental in vitro studies, and definitive conclusions regarding its clinical efficacy cannot yet be drawn. Well-designed pharmacological investigations, molecular studies, animal experiments, and randomized clinical trials are required to validate its mechanisms, establish standardized formulations, and determine its role as a safe adjunctive therapy for infection prevention and immune support in children.

Limitations

This review has several limitations that should be considered while interpreting its findings.

- The available evidence is predominantly based on in vitro studies, which may not accurately reflect the complex biological conditions present in the human body.
- Only a limited number of studies have directly evaluated the antibacterial activity of *Swarnaprashana* as a complete formulation, with most evidence derived from investigations of its individual components.
- Considerable variation exists in the preparation methods, composition, dosage, and quality of *Swarnaprashana* across different studies, making direct comparison difficult.
- Clinical evidence demonstrating efficacy against infectious diseases in children is limited, and high-quality randomized controlled trials are lacking.
- Because this is a narrative review integrating Ayurvedic concepts with modern scientific evidence, some mechanistic interpretations remain theoretical and require further experimental validation.

Future Scope

- Future research should focus on generating robust scientific evidence to establish the antibacterial and immunomodulatory potential of *Swarnaprashana*.
- Standardized methods for the preparation, quality control, and physicochemical characterization of *Swarnaprashana* should be developed to improve reproducibility between studies.
- Advanced analytical techniques such as LC–MS/MS, HPTLC, GC–MS, ICP–MS, transmission electron microscopy (TEM), scanning electron microscopy (SEM), X-ray diffraction (XRD), and zeta potential analysis should be employed to characterize the formulation and its active constituents.
- Molecular studies should investigate the effects of *Swarnaprashana* on bacterial membrane integrity, oxidative stress pathways, quorum sensing, biofilm formation, gene expression, and antimicrobial resistance mechanisms.
- Comparative studies of multidrug-resistant bacterial pathogens should be conducted to explore their potential role in addressing antimicrobial resistance.
- Animal studies are needed to evaluate pharmacokinetics, biodistribution, toxicity, and immunomodulatory mechanisms before large-scale clinical investigations.

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