

Nanoparticle-Based Therapeutics for Disorders of the Female Upper Genital Tract: A Comprehensive Review

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Abstract

The female reproductive system is susceptible to a range of disorders, including uterine fibroids, endometriosis, polycystic ovarian syndrome (PCOS), and various gynecological cancers. Traditional drug delivery methods often face challenges such as limited bioavailability, systemic side effects, and poor targeting due to biological barriers like mucus layers, fluctuating pH, and immune responses. Nanotechnology offers a transformative approach to overcome these limitations by enabling site-specific and controlled drug release. This review explores the anatomy of the female upper genital tract (UGT), common associated disorders, and the barriers that hinder effective drug delivery. It highlights the potential of nanoparticle-based drug delivery systems—such as liposomes, polymeric nanoparticles, dendrimers, and nanoemulsions—to improve therapeutic outcomes. Nanoparticles can penetrate mucosal barriers, increase drug retention time, and allow targeted therapy through surface modification and responsive release mechanisms. Specific applications of nanocarriers in treating cervical, ovarian, and endometrial cancers, as well as non-malignant conditions like PCOS, fibroids, and salpingemphraxis, are discussed in detail. Examples include gold and zinc oxide nanoparticles for cancer treatment, curcumin-loaded NPs for PCOS, and magnetic NPs for targeted gene delivery. Despite promising preclinical results, concerns regarding toxicity, hormonal disruption, and regulatory challenges remain and warrant further clinical evaluation. In conclusion, nanotechnology holds immense potential to revolutionize female reproductive healthcare by offering non-invasive, efficient, and safer alternatives to conventional therapies. Continued interdisciplinary research is essential to translate these innovations into clinically viable treatments for improving women's reproductive health outcomes.

Keywords: Nanoparticles, mucosal barriers, cancer treatment.

INTRODUCTION:

The female reproductive system is a biological system responsible for the production, transport, and storage of reproductive cells, and it enables the fusion of egg and sperm for fertilization¹. Anatomically, the female reproductive system can be categorized into two main regions: the lower region and the upper region. The lower region includes the vaginal canal and the ectocervix, while the upper region consists of the endocervix, uterus, fallopian tubes, and ovaries².

Several common disorders are capable of affecting the female reproductive system, such as pregnancy complications, endometriosis, uterine fibroids, and cervical cancer. Additionally, ovarian issues like polycystic ovarian syndrome (PCOS) and ovarian cancer, along with infections such as HIV, pelvic inflammatory disease, vaginitis, urinary tract infections (UTIs), sexually transmitted diseases (STDs), and human papillomavirus³. These disorders typically influence the areas of the upper genital tract, like the uterus, fallopian

tubes, and ovaries, leading to hormonal imbalances, infertility, and other health complications⁴.

Biological barriers that influence the efficacy of vaginal drug delivery consist of the mucus layer, epithelium, microbiome, immune system, and various physiological factors. The mucus layer arrests foreign particles through adhesive and steric interactions. Cervicovaginal mucus coats the vaginal epithelium, serving as a protective barrier against pathogens and foreign matter. The mucin and glycoproteins present in the mucus develop into both physical and chemical barriers that can hinder the effectiveness of drug delivery systems. To address these challenges, various innovative drug delivery systems are being utilized⁵.

Nanotechnology is a science or study of tiny objects that range from 0.1 to 100 nm⁶. Nanotechnology-based drug delivery systems can be given in many ways to improve drug bioavailability, circulation time, and targeting of pathological tissues and it doesn't increase the systemic toxicity⁴. Nanoparticles are effective for drug delivery,

which has the ability to overcome physiological barriers and target the drug to specific cells⁷.

The flexibility of nano-sized systems enables easy modification of their physical as well as chemical properties to increase the drug delivery ability. Such modification involves:

I} Altering particle size to enhance permeability and targeting.

II} Altering surface charge to increase solubility.

Modifying the chemical properties of a component's surface to attain desired functionalities like improved adhesion, increased biocompatibility, or specific chemical reactivity, which will result in increasing biological circulation time and improving drug targeting.

ANATOMY AND PHYSIOLOGY OF FEMALE UPPER GENITAL TRACT:

The upper genital tract consists of the endocervix, uterus, fallopian tubes, and ovaries. The cervix serves as a link

between the lower and upper genital tracts. Anatomically, the cervix is divided into three compartments: the ectocervix, endocervix and the cervical transformation zone. The endocervix connects the lower genital tract and uterus. The uterus is the primary reproductive fibromuscular organ essential for female reproductive functions. The uterus consists of three parts: serosa, myometrium, and uterine mucosa (endometrium). The uterine mucosa produces uterine fluid during menstrual cycle and pregnancy². There may be numerous disorders linked to upper genital tract, such as:

- **Uterus:** Pregnancy cancer, Uterine Fibroids
- **Endometrium:** Endometriosis, Endometrial Cancer
- **Cervix:** Cervical cancer
- **Ovary:** Ovarian Cancer, Poly cystic ovarian syndrome (PCOS), Premature ovarian failure
- **Fallopian Tubes:** Salpingemphraxis³.

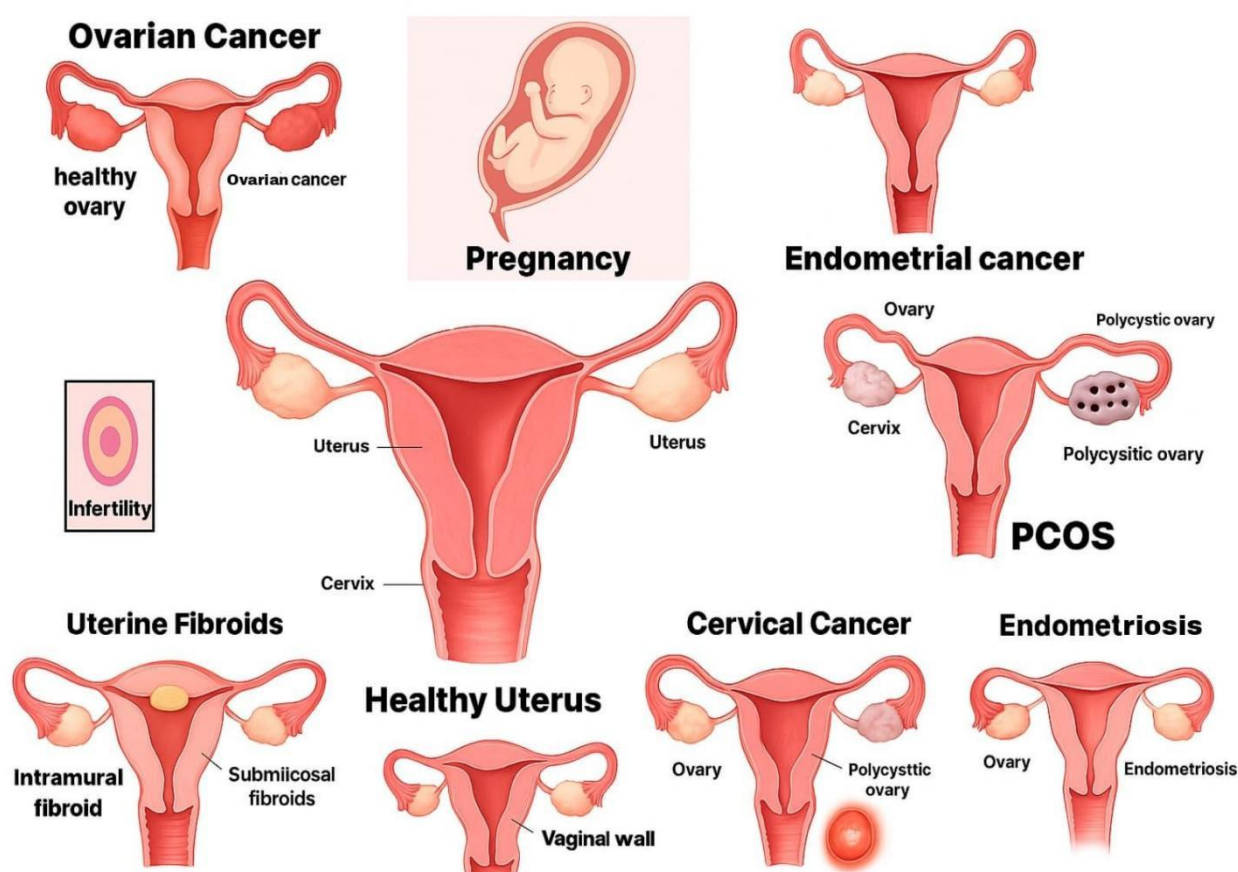


Figure 1: Disorders of female upper genital tract³.

DISORDERS ASSOCIATED WITH FEMALE GENITAL TRACT:

1. UTERINE FIBROIDS:

Uterine fibroids, which is also known as uterine leiomyomas, are malignant tumors of the uterine smooth muscles. Women of reproductive age are more

susceptible to these uterine fibroids. Fibroids consist of smooth muscle, fibroblast components, and fibrous extracellular matrix, all of which aid in the pathogenesis process. When it comes to pathogenesis, the size of fibroids, their location, and clinical symptoms are incredibly diverse. While some women do not exhibit any symptoms, others suffer from hypermenorrhea or

dysmenorrhea. Depending on the size and location of the fibroids, the symptoms and their intensity may vary. Heavy menstrual bleeding, which can result in anemia, exhaustion, or uncomfortable periods, is the most typical initial symptom. Additional possible symptoms include pelvic pain or pelvic pressure, lower back pain, and pain during intercourse⁸. Development of fibroids above a certain size causes higher pressure on the bladder or bowel and may result in pain, constipation or increased micturition frequency. It is possible that infertility, repeated miscarriages, and unfavorable obstetric outcomes could be associated with uterine fibroids⁹.

2. ENDOMETRIOSIS:

Endometriosis is a condition where tissue like the inner lining of the uterus develops or grows outside of the uterus. It can cause frequent pain, and these growths can also extend beyond the pelvic region in rare cases. It usually affects women and girls of reproductive age in the range of 10% to 15% and also women with menopause. This condition mainly effects the ovaries, pelvic lining, and fallopian tubes. Patient's symptoms include hot flashes, dryness of the vagina, bone loss, headaches, high testosterone levels, hirsutism, and irreversible deepening of voice¹⁰.

3. ENDOMETRIAL CANCER:

Endometrial cancer is a condition where malignant or tumor cells originate in the tissues of the endometrium, the inner lining of the uterus. It is the most common type of carcinoma affecting the uterus, and it is simply known as "uterine cancer"¹¹.

4. CERVICAL CANCER:

The 4th most general and common gynecological cancer found in women and females of reproductive age is cervical cancer. It is a type of carcinoma that originates in the lower part of the vagina, the cervix connecting to the uterus. HPV (Human Papillomavirus), a sexually transmitted infection, is the main or the primary cause for this cervical cancer. The initial stage of this condition often does not show up with any symptoms, but when it progresses, the signs and symptoms may include heavier menstrual bleeding, pelvic pain, foul-smelling vaginal discharge, pain during intercourse, and many more¹².

5. OVARIAN CANCER:

It is a type of cancer that generally occurs after menopause in women. Ovarian cancer originates in the ovaries, which are responsible for producing eggs (ova) and female hormones. There will be no symptoms during its early stage, but later symptoms like abdominal swelling, pelvic pain or pressure, problems with bowel habits, frequent urination, back pain, the presence of a lump in the pelvic area, and fatigue may appear as it progresses¹³.

6. POLYCYSTIC OVARIAN SYNDROME (PCOS):

PCOS is the most complicated and common hormonal disorder, affecting almost 15% of the females, which mainly produces an excess of male hormones (androgens), irregular periods, and the development of immature egg follicles on the ovaries. It can potentially increase the risk of infertility, cardiac problems (can increase blood pressure), and endometrial cancer¹⁴.

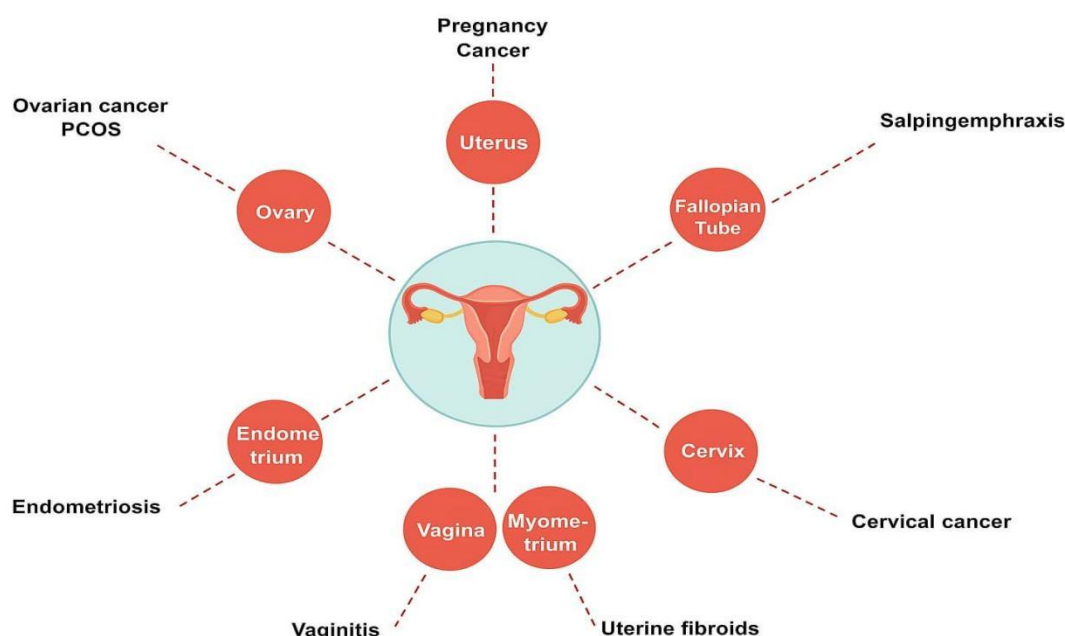


Figure 2: Parts of female genital tract with diseases associated with them

MUCOSAL BARRIER

It is a barrier in UGT that prevents mechanical, chemical and microbial injury. The mucosal barrier prevents drug permeation, which decreases the drug availability in that region, and mucus permeation of the drug is essential for

effective drug delivery or drug targeting in the female UGT. There are a number of delivery systems to overcome that barrier to increase permeation and drug availability, such as:

- Zeta potential changing drug delivery system
- Nano particulate system
- Enzymatically incorporating active component system

Among them, the nanoparticle system has the ability to target the reproductive system successfully by

increasing therapeutic efficacy with decreased side effects. It has sustainable therapeutic action and increased bioavailability².

NOVEL DRUG DELIVERY SYSTEM:

Some of the novel approaches for effective drug delivery in the female genital tract are listed below:

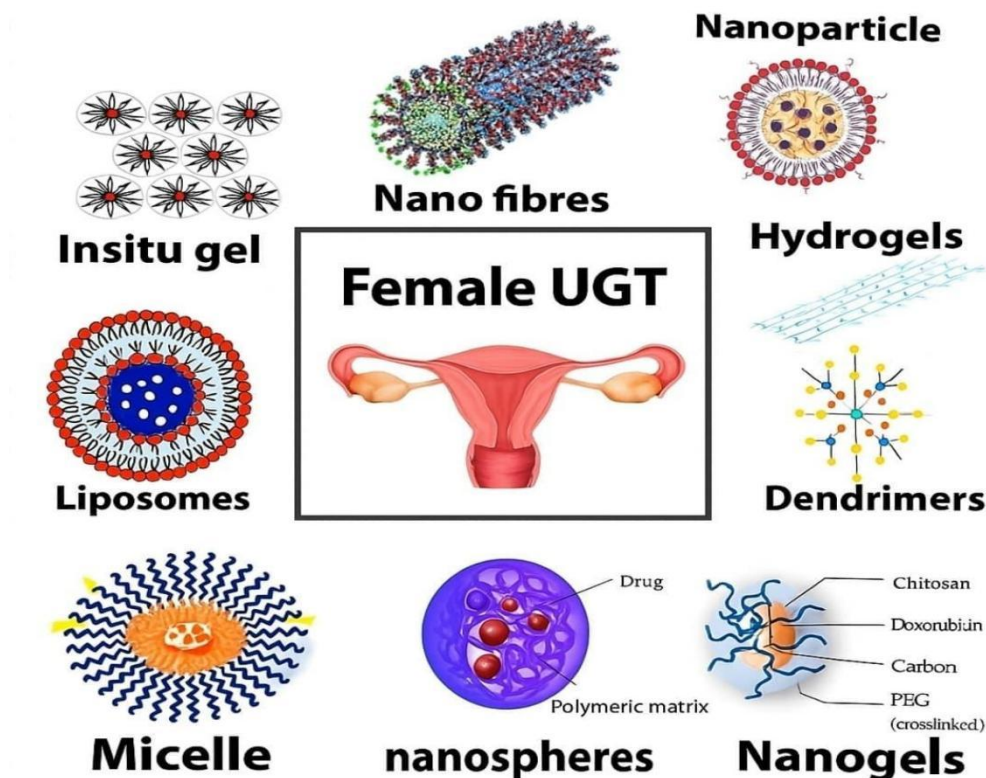


Figure 3: Approaches for drug delivery to female genital tract

- Nanoparticles
- Liposomes
- Niosomes /Micelles
- Nanoemulsions
- Dendrimers
- Dendritic Polymers
- Nanofibers
- Hydrogels
- In-situ gels
- Nanospheres

Of these, nanoparticle approach has advantage compared to others¹⁵.

NANOTECHNOLOGY/NANOSCIENCE:

The word nano is derived from the *Latin* word *nanus*, meaning tiny or dwarf. It was first presented by Nobel Laureate Richard Feynman in 1959⁶. Nanoscience is a branch of science that deals with the study of particles in nanoscale (1 to 100 nm)⁴. It has significant applications

in various sectors such as food, agriculture, environment, biotechnology, biomedical, and medicine⁵. The major goal of a nanoparticle system is to control particle size and release of active pharmaceutical ingredients in order to achieve target drug delivery and site-specific action⁷. The nanoparticle is composed of three layers¹⁶:

1. Surface layer
2. Shell layer
3. Core

Nano carriers:

The conventional dosage forms to treat genital disorders have multiple limitations resulting in incomplete or improper or insufficient drug delivery and increased doses of drug. To overcome these disadvantages, various novel approaches have been developed for effective drug delivery¹⁷.

Nano carriers for drug delivery:

Nanoparticles are the effective drug delivery system having the ability to defeat physiological barriers, usually for local drug delivery. Mucosal routes are used, but this

route can also be habituated for systemic drug delivery. To achieve this goal, numerous nanocarriers have been imposed are introduced.

- Polymeric nanoparticles
- Liposomes
- Dendrimers
- Nano emulsion
- SEDDS
- Nanofibers¹⁸

Polymeric nanoparticles:

PNPs have proven the magnified drug concentration in target tissues, improved drug stability, and defense against rapid degradation. The polymeric nanoparticles are submicron-sized colloidal substances where the active agent or pharmaceutical agent is dissolved in their dispersion, encapsulated inside the matrix or polymer, adsorbed onto the surface layer, or chemically attached. PNP's size ranges between 10 and 1000 nm. Generally, 50 to 600 nm is advised as pharmaceutically acceptable.

PNPs consist of both nanospheres and nanocapsules. Nanocapsules are vesicular systems possessing an oil core surrounded by a thin polymer, whereas a dense, compact polymeric matrix¹⁹ prepares nanospheres.

CLASSIFICATION OF NANO PARTICLES:

- Organic nanoparticles
- Inorganic nanoparticles

1. Inorganic nanoparticles:

These are the nanoparticles that do not contain carbon atoms. These have versatile features, for example, easy functionalization, exceptional physiochemical properties like electrical, magnetic nature, and modifiable morphology. Advantageous morphology makes it potential for being nanomedicine².

Types of inorganic nanoparticles:

- a) Metal-based inorganic nanoparticles
- b) Metal oxide-based nanoparticles
- c) Semiconductor nanoparticles
- d) Ceramic nanoparticle
- e) Layered double hydroxides
- f) Mesoporous silica nanoparticle²⁰

a) Metal-based nanoparticle: Nanoparticles prepared from metals like gold, silver, platinum, and titanium are used for identification of cervical cancer.

E.g., gold nanoparticle encapsulating doxorubicin with resveratrol help in treating cervical cancer.

These nanoparticles are also capable of decreasing toxicity in normal cells, whereas apoptosis can be induced in HeLa and CaSki cell lines. Pure metal

nanoparticles also consist of magnetic properties and have potential applications as magnetic nanoparticles²¹.

b) Metal oxide-based nanoparticles: Some of the metal oxide nanoparticles, like zinc oxide (ZnO), titanium dioxide (TiO₂), copper oxide (CuO), magnesium oxide (MgO), and iron oxide (Fe₂O₃) are present.²⁰ Among these, zinc oxide (ZnO) nanoparticles are most widely used in the female UGT cancer because, when compared to other metal oxides, zinc oxide is very cost-effective and nontoxic²¹.

This zinc oxide is used for medicinal purposes like anti-microbial, anti-diabetic, anti-inflammatory, anti-aging, wound healing, and some other medicinal purposes. Similarly, other types of inorganic nanoparticles are used in the diagnosis and treatment of various disorders of the female UGT²².

2. Organic Nanoparticles:

These are the solid particles that contains organic compounds, mainly lipids or polymers²³. These are mostly used because of their cost-effectiveness, and also the production process is shorter. These are having more benefits than the inorganic nanoparticles because of their non-toxicity and biocompatibility nature²⁴.

Mechanism of Nano Drug delivery system Targeting Upper Genital Tract:

1). Mucoadhesion and Permeation:

The cervical and vaginal mucosa acts as a barrier for drug absorption. Hence, nanoparticles can be developed with the property of mucoadhesion (e.g., chitosan coating), which in turn increases the retention and absorption.

2) PH-Sensitive and Enzyme-Responsive release:

The female reproductive system has variable pH.

i.e., uterine pH - 7.0.

Vaginal pH - 4.5.

Hence, NDDS can be formulated in such a way that it releases drugs in response to pH or gets triggered by the local enzymes. It leads to enhancing the site-specific therapy of NDDS.

3) Intravaginal to Tract Transport:

Muco-inert nanoparticles (e.g., PEG coated) can pass through the lumen of the vagina into the uterus and fallopian tubes, this is known as the "uterine first- pass effect." This effect helps in noninvasive delivery to the upper tract²⁵.

Advantages of nano drug delivery in the female genital tract:

- Enhances drug stability and drug solubility.
- Controlled and sustained drug delivery.
- Improved patient compliance.
- Targeted and localized delivery of drug.

- Reduces side effects.
- Overcoming mucosal and biological barriers.
- Enhanced mucosal penetration and retention²⁶.
- Protection from sensitive drugs.
- Improved bioavailability.

Disadvantages of nano drug delivery in the female genital tract:

- Potential toxicity and reproductive risks.

- The presence of nanoparticles in the uterus can potentially induce toxicity and negatively impact reproductive function²⁷.
- Disruption of hormone regulation.
- Impact on reproductive cells and oogenesis.
- Challenges in drug delivery and targeting.
- Lack of standardized guidelines²⁸.

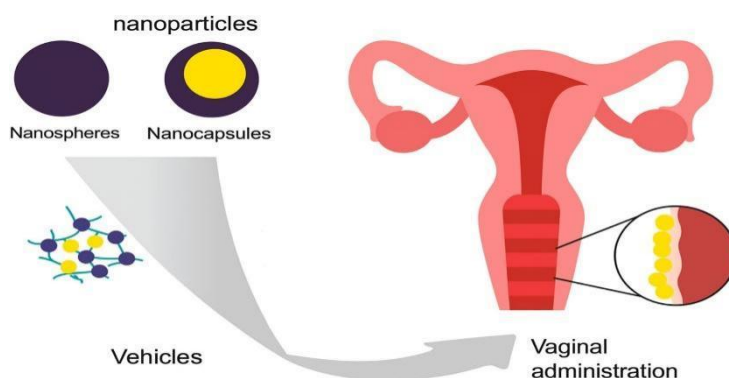


Figure 4: Nanoparticles through vaginal route of administration

Applications of nanoparticles in UGT disorders:

The nanoparticles have numerous applications, which include

1. Targeted drug delivery system: By delivering therapeutic compounds straight to the ovaries or uterus, nanoparticles can lessen systemic side effects. Particularly helpful in the treatment of pelvic inflammatory disease (PID), ovarian cancer, and endometrial cancer. The goal of targeted medicine delivery is to minimize exposure to healthy tissues while

delivering a therapeutic agent precisely to a sick spot. As carriers, nanoparticles can be designed to:

- 1) Transcend physiological boundaries, such as the uterine lining or vaginal mucosa.
- 2) Bind to particular cells or receptors (e.g., inflammatory endometrium, cancer cells)
- 3) Drugs can be released gradually, under control, or in response to stimuli (e.g., pH or enzyme-triggered)²⁹.

Table 1: Applications of nano particles in Genital tract disorders.

Application	Type of nanoparticle	Advantages	Disadvantages	Reference
Oocyte IVM enhancement	ZnO, Se-ZnO, Fullerenol, Mel-LNC, PLGA	Better ROS control, blastocyst yield	Dose-dependent toxicity	[30]
Ovarian regeneration	CeO ₂ NPs	Antioxidant, improved oocyte health	Early-stage; translation pending	[31]
Endometrial repair / fertility	hydrogels, ApoBDs	Regeneration, implantation support	Biocompatibility, immunogenicity	[32]
Treatment of fibroids / endometriosis	Magnetic NPs, dendrimers, films	Targeted therapy potential	Preclinical stage, off-target effects	[33]

2. Application in cancer therapy:

Nanoparticles are used for diagnosis and treatment of various types of cancer like:

- Ovarian cancer
- Endometrial cancer
- Cervical cancer

Cervical cancer

It is one of the most common gynecologic cancers with most patient fatalities. The inadequacy of the vaccine and various factors of the site affect drug absorption and action³⁴. Nanomedicine involves utilizing nanoparticles between 10 and 100 nm to create distinctive interactions with biological systems³⁵. Various drugs are formulated

in the form of nanoparticles, which helps in the enhancement of the activity of the drug³⁶. For attaining high effectiveness with fewer side effects, nanoparticles are utilized, which is not possible in conventional dosage

forms. These nanoparticles have various merits, like increased stability of the drug by reducing degradation, better solubility of hydrophilic drug, fewer side effects, and targeting of the cancer cells³⁷.

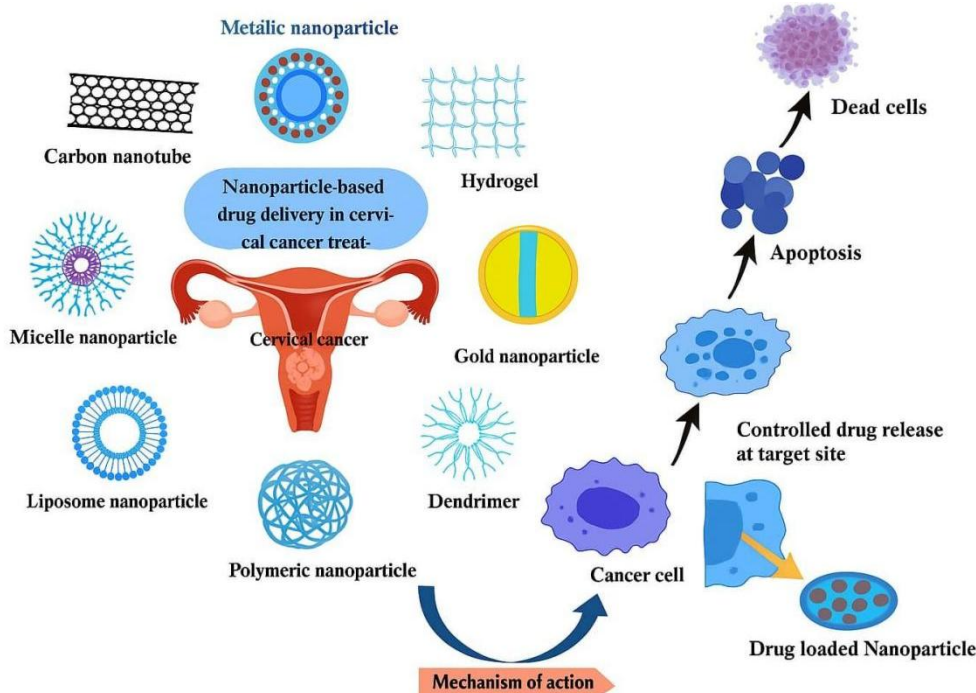


Figure 5: Mechanism of action of nano particles in cervical cancer

The above fig illustrates the different types of nanoparticles used in the cervical cancer. The drug-loaded nanoparticles provide a controlled release of the drug, which enhances the effectiveness of the drug. The drug shows its action by inducing apoptosis of the cancer cells. There is a continual exploration of the various applications of the nanoparticles in cervical cancer³⁸.

b. Endometrial cancer

One of the most common gynecologic cancers is endometrial carcinoma (EC). Conventional medications, such as hormone therapy, radiation, chemotherapy, and surgery, frequently include drawbacks, such as chemo resistance and systemic toxicity. Drug resistance can be overcome, off-target effects can be minimized, and targeted administration can be improved via nanoparticle (NP)-based methods. When compared to free PTX or non-targeted formulations, polymeric nanoparticles such as folate-modified PLGA have demonstrated improved paclitaxel (PTX) delivery to EC cells via folate receptor-mediated absorption, leading to greater tumor suppression³⁹.

Co-delivery systems that use NPs that are sensitive to redox or pH, such as those that transport doxorubicin and navitoclax, can boost apoptosis in EC models in a synergistic way⁴⁰.

Strategies for synthetic lethality have been explored in type II ECs, which frequently include p53 mutations. In USC xenograft models, PLGA NPs co-loaded with PTX and nintedanib (a VEGFR/FGFR/PDGR inhibitor) markedly decreased tumor development and increased survival⁴¹.

Additionally, nanoparticles help target metabolic processes. For instance, in high-glucose settings, redox-

responsive NPs co-delivering metformin and a PDK1 inhibitor (JX06) reduced tumor development, indicating relevance to diabetic EC patients with the potential for future EC-specific treatments, inorganic NPs such as superparamagnetic iron oxide nanoparticles (SPIONs) offer dual functionality in drug delivery and hyperthermia therapy⁴².

Through apoptosis and cell cycle arrest, phytochemical-based NPs, including thymoquinone-stabilized selenium nanoparticles, have shown increased lethal effects in HEC-1B EC cells.

In the end, platforms based on nanoparticles in EC show potential for improved efficacy, less toxicity, and tailored administration. However, more research and clinical application are required⁴³.

c. Ovarian cancer

Due to its nonspecific symptoms and lack of early diagnostic techniques, ovarian cancer (OC) is a major health burden in India and is frequently detected at an advanced stage. Nanotechnology presents intriguing approaches to less toxicity and better medicine delivery that is increased bioavailability. Thermo-sensitive delivery of drugs increases the efficiency. With their inventive nanoparticle (NP) technologies, researchers are making significant contributions to this discipline. To actively target ovarian cancer cells, Bhattacharya et al. (IIT-BHU) created gemcitabine-loaded chitosan-poly sarcosine nanoparticles coupled with the EGFRvIII ligand. Their research revealed promise for enhancing therapy specificity and conquering medication resistance⁴⁴.

Nanostructured lipid carriers (NLCs) with dual targeting capabilities were investigated by Ray et al. (Lovely

Professional University). These lipid-based NPs enhanced the bioavailability, cellular absorption, and regulated release of chemotherapeutics like doxorubicin in OC models by integrating ligands like folic acid⁴⁵.

These contributions are in line with international initiatives to create effective and individualized treatments for ovarian cancer and demonstrate the country's developing proficiency in medication delivery using nanoparticles. Although preclinical results are promising, further translational research and clinical trials are necessary to confirm their therapeutic effectiveness and patient safety.

3. Applications of Nanoparticles in Endometriosis

In the endometriosis treatment, the main drawbacks include targeting, poor stability, and decreased biological activity. But the nanomaterials, drug delivery carriers, can overcome these limitations. Nanoparticles are excellent carriers of therapeutic agents. These approaches allow the combination of therapeutic agents for drug delivery that targets multiple therapeutic pathways in endometriosis, which results in novel combination therapies. Nano platforms significantly reduce unwanted side effects of the drug and also increase selectivity and accumulation of the drug in the disease site. Few NPs, such as cerium oxide NP (nanoceria), produce direct pharmacological action i.e., they can decrease endometrial lesions by reducing oxidative stress and by inhibiting angiogenesis. The NPs coated with ligands were designed in such a way that they bind specifically to endometrial cells. This approach increases accurate visualization and localization of endometriosis and imaging capabilities, and hence it gives a better understanding of the disease. Researchers have successfully developed magnetic iron oxide (Fe_3O_4) NPs modified with hyaluronic acid (HA) for utilizing it as negative contrast agents in T2-weighted endometriosis MRIs. These NPs had lesser toxicity and increased relativity.

Epigallocatechin gallate (EGCG), doxycycline (DOX), poly (lactic-co-glycolic acid) (PLGA) nanoparticles, and dual drug-loaded NPs (DOX-EGCG NPs) were utilized in

treating endometriosis, and it was found that dual drug-loaded NPs were more effective than single drug-loaded NPs. NP immunotherapy for endometriosis increases the body's immune response against endometrial lesions. A study found that endostatin-loaded polyamidoamine (PAMAM) dendrimers along with polyethylene amine-polyethylene glycol-arginine-glycine-aspartic acid (PEI-PEG-RGD) carrying miR-200c mimic RNA (mRNA@PEI-PEG-RGD) were utilized in gene therapy for treating endometriosis. This approach has shown promising results in preclinical studies, but clinical trials are still required to validate their safety and efficacy in humans⁴⁶.

4. Nanoparticles in Uterine Fibroid Therapy:

Uterine fibroids are common benign tumors in women that often require invasive treatments. Nanotechnology offers promising non-surgical alternatives by improving targeted drug delivery and reducing side effects. Due to their regulated drug release and improved absorption, PEG-PLGA nanoparticles loaded with 2-methoxyestradiol (2-ME) have demonstrated a significant tumor reduction (up to 51%) in patient-derived fibroid models in recent Indian and international research. In order to improve transfection efficacy in fibroid cells and stem-like tumor cells while lowering the necessary virus dose, magnetic nanoparticles have been utilized to improve gene delivery (magnetofection)⁴⁷. To improve treatment precision, further studies investigate nanogold conjugates with TNF- α as cryo-adjuvants for fibroid ablation⁴⁸.

Although further clinical research is required, these nanoparticle systems exhibit great promise for safer, fertility-preserving fibroid therapy.

5. Nanoparticles in Polycystic Ovarian Syndrome (PCOS) Treatment:

PCOS is a prevalent endocrine condition that results in insulin resistance, ovarian dysfunction, and hormonal imbalance. Novel strategies to enhance drug distribution, lessen adverse effects, and target biological pathways linked to PCOS are provided by nanotechnology-based therapeutics.

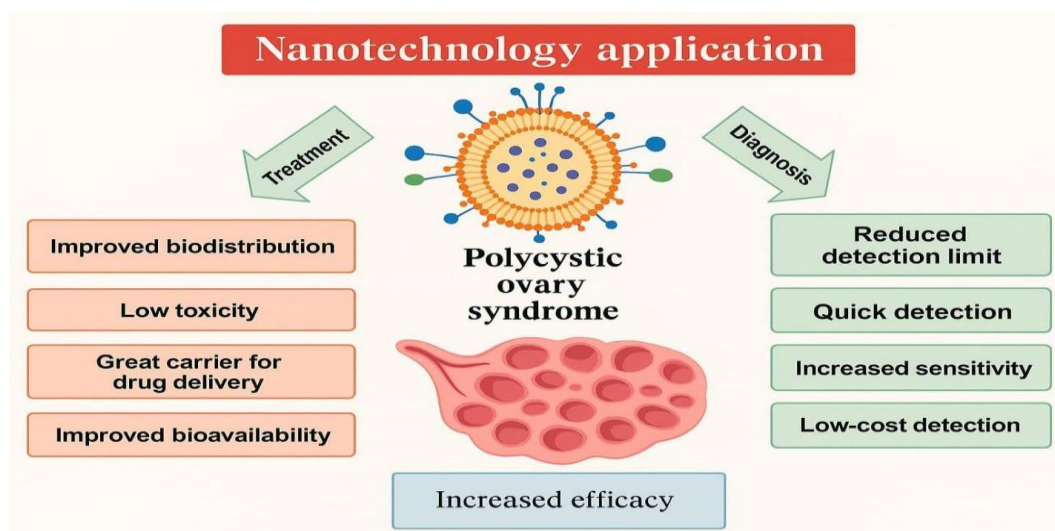


Figure 6: Application of nanoparticles in PCOS

Lipid-based nanoparticles have been demonstrated in studies to improve glucose metabolism and ovarian function by increasing the bioavailability of insulin-sensitizing medications such as pioglitazone and metformin⁴⁹. In PCOS models, curcumin-loaded nanoparticles reduce oxidative stress and hormonal abnormalities by exhibiting anti-inflammatory and antioxidant properties⁵⁰. Furthermore, microRNA (miRNA)-delivering nanoparticles have the ability to alter the expression of genes related to steroidogenesis and follicular development, thereby opening the door to precision medicine⁵¹.

Despite encouraging preclinical evidence, more clinical trials are required to validate the safety and effectiveness of PCOS therapies based on nanoparticles.

6. Nanoparticles in the Management of Salpingemphraxis:

Female infertility is frequently caused by fallopian tube occlusion, or salpingemphraxis. Conventional therapies, such as assisted reproductive technologies (ART) or tubal surgery, can be expensive and intrusive. Nanoparticle-based treatments are being investigated recently as targeted, less invasive substitutes.

Research has demonstrated that therapy can be localized at the location of tubal occlusion by employing external magnetic fields to guide magnetic nanoparticles (MNPs). These MNPs can remove fibrin clots and biofilms that cause tubal obstruction by delivering enzymatic or anti-inflammatory chemicals⁵². In order to ensure localized drug release and reduce systemic adverse effects, chitosan- and PLGA-based nanoparticles have also been investigated for targeted antibiotic administration in tubal infections (such as salpingitis). These nanotechnologies, while still in the experimental stage, could provide women with salpingemphraxis safer, fertility-preserving alternatives.

Nanoparticles (NPs) are transforming the diagnosis and treatment of various female reproductive health issues by offering targeted, efficient, and less invasive alternatives to conventional therapies. From cancer management to infertility-related conditions, their applications are rapidly advancing⁵³.

CONCLUSION:

Nanotechnology is opening a new chapter in women's healthcare, offering smarter and more targeted ways to treat reproductive disorders. By overcoming natural barriers in the body, these tiny drug carriers can deliver medicine exactly where it's needed—with fewer side effects and better results. While some challenges remain, the progress so far is inspiring. With continued research and care, these innovations could bring real hope and healing to millions of women facing complex reproductive health issues.

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