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Nanotechnology: Recent Advances, Opportunities and Challenges

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Abstract

Nanotechnology, the science of the minuscule, has catalysed a revolution across diverse fields, from pharmacy to veterinary science. This abstract encapsulates the dynamic interplay between nanotechnology and healthcare, unveiling its transformative impact on drug delivery, cosmeceuticals, veterinary medicine, dentistry, and biotechnology. In pharmacy, nanotechnology pioneers targeted drug delivery systems, amplifying therapeutic efficacy while mitigating adverse effects. Nano-cosmeceuticals redefine beauty standards, infusing skincare, haircare, lip care, and nail care products with unparalleled penetration and stability. Veterinary science embraces nanotechnology's potential, enhancing diagnosis, treatment delivery, and disease control in animals. Concurrently, dentistry explores nanomaterials' potential, revolutionizing oral health treatments with improved qualities and novel applications. At the nexus of biology and nanotechnology, nanobiotechnology unveils a new frontier, offering transformative tools for studying biological phenomena and designing innovative therapies. This abstract serves as a portal into the dynamic landscape of nanotechnology in healthcare, where innovation converges with the infinitesimal to redefine the boundaries of possibility.

Keywords: Nanotechnology, targeted drug delivery, adverse effects, solid lipid nanoparticles, drug loading capacity

INTRODUCTION

The nanoparticles that are utilized as drug delivery vehicles are typically less than 100 nm in one dimension and comprise various biodegradable components, including metals, lipids, and natural or manufactured polymers. Because nanoparticles are absorbed by cells more quickly than bigger micro molecules, they have the potential to be employed as efficient delivery and transportation vehicles. In therapeutic contexts, medications can be integrated into the particle matrix or affixed onto the particle's surface. An effective drug delivery system should regulate how drugs are released into the biological surroundings. Many nano systems with varying biological characteristics and compositions have been thoroughly studied for medication and gene delivery applications [1–5].

Numerous therapeutic plant products' composition and biological activities have already been determined by the fields of phytochemistry and phytopharmacology. Most biologically active ingredients found in extracts, including tannins, terpenoids, and flavonoids, are very soluble in water but have poor absorption due to their high molecular sizes, inability to cross lipid membranes, and poor

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absorption, which reduces their bioavailability and effectiveness. Herbal remedies have demonstrated good effectiveness in assays conducted in vitro, which are not repeatable in in vivo investigations, according to certain publications. Additionally, some necessary ingredients are hardly ever employed since they don’t work well with other ingredients in the formulation or have unfavourable qualities [6, 7].

To address this challenge, various nanotechnological methods have been created, such as liposomes, polymeric nanoparticles, microemulsions, precursor systems for liquid crystals (PSLCs), liquid crystal (LC) systems, and solid lipid nanoparticles (SLNs). These methods can change a substance’s behaviour in a biological environment and allow the use of compounds with different qualities in the same formulation. These technological developments have revolutionized the way that medications are delivered. The novel medication delivery techniques have the potential to increase the efficacy of active substances while also reintroducing inactive components that were previously removed from formulations. The potential to refine novel drugs before they are commercialized or used therapeutically makes this strategy even more alluring. Reducing adverse effects, enhancing selectivity and efficacy, preventing thermal or photodegradation, and managing the release of active ingredients are a few examples of these enhancements [8–11].

Pharmaceutical nanotechnology includes the use of nanoscience in pharmacy to create nanomaterials and technologies, such as biosensor materials, diagnostic tools, and drug delivery systems. Pharmaceutical nanotechnology has made it possible to treat diseases at the molecular level with more precision and focus. It assists in identifying the antigen linked to illnesses including cancer, diabetes, and neurodegenerative disorders in addition to identifying the bacteria and viruses linked to infections. Size reduction is useful in pharmacies because medications in the nanoscale size range operate better in a range of dose formats.

A Variety of Benefits of Nanotechnology in Pharmacy Are Provided by

1. A larger surface area.
2. Increased solubility.
3. A faster rate of disintegration.
4. The oral bioavailability has increased.
5. Less dose is needed, and fewer doses are needed.
6. Preventing the medication from deteriorating.
7. A quicker start to the therapeutic effect of Drug targeting is achieved.
8. Drugs are passively targeted to the macrophages found in the spleen and liver [12].

A Few Significant Drug Delivery Systems That Were Created with Nanotechnology Tenets Are

1. Small particles (nanoparticles).
2. Nanoparticles of solid lipid.
3. The absence of crystals (nanocrystals).
4. Nano-suspensions.

Nano emulsions when compared to bigger particles of the same material, nanoparticles – defined as particles with a diameter of less than 100 nm – show new or improved size-dependent features. These provide the medication with:

Increased bioavailability for drugs who’s non-nanoparticulate dosage forms are unsatisfactorily unstable or have unacceptably poor bioavailability, stable dosage forms, smaller dosage forms (such as tablets), decreased toxicity, and dose proportionality are all desirable [13].

Various Nanoparticle Types in Drug Delivery Systems

Because of their special characteristics, which include their small size, vast surface area, and capacity for surface modification, nanoparticles are commonly used in drug delivery systems. Numerous kinds of nanoparticles have been investigated for use in medication delivery systems. These are a few typical kinds (Figure 1).

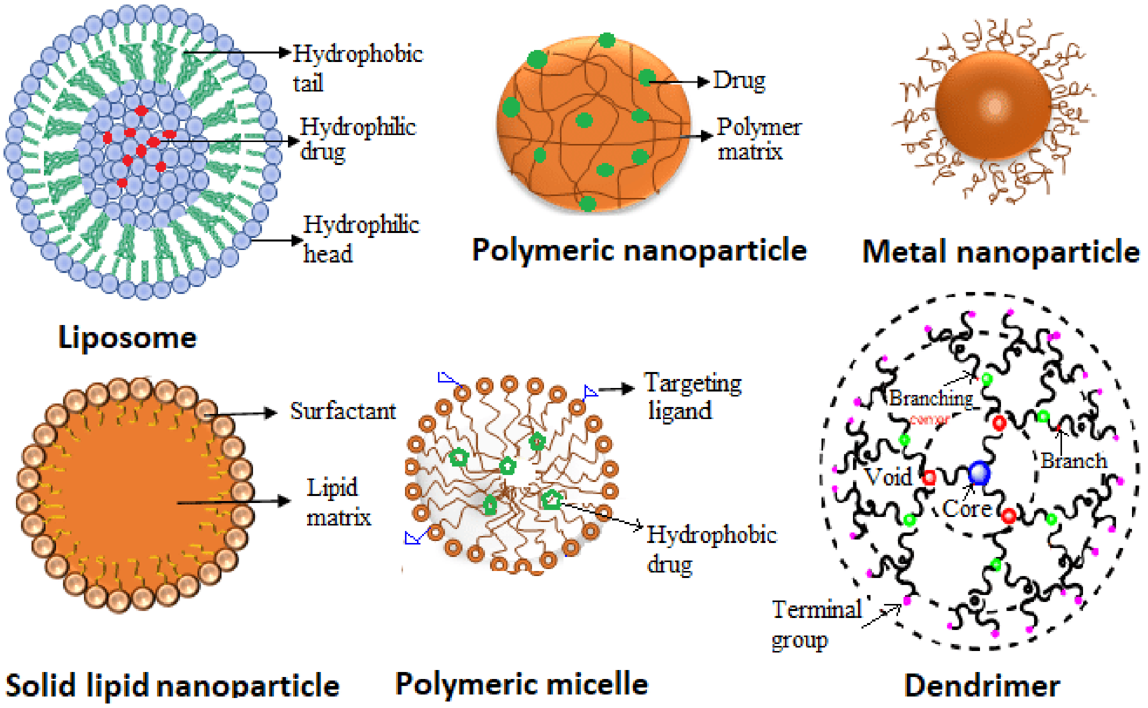

Figure 1. Schematic representation of different types of nanoparticles [14].

ADVANCEMENT IN NANOTECHNOLGY

Photodynamic Therapy of Cancer via Nanotechnology

Photodynamic therapy (PDT) is an innovative approach in cancer treatment, involving the use of a photosensitizer (PS) that targets tumors and nearby blood vessels. Activation of the PS occurs via light of specific wavelengths. To enhance PDT effectiveness, researchers are exploring nanostructured drug delivery systems, such as hydrogels, liposomes, liquid crystals, dendrimers, cyclodextrin, polymeric nanoparticles (PNPs), solid lipid nanoparticles (SLNs), nanostructured lipid carriers (NLCs), gold nanoparticles (AuNPs), among others. These nanostructures aim to improve PS delivery across endothelial and epithelial barriers, potentially allowing for combined administration of multiple medications alongside PDT [15].

During photodynamic therapy (PDT), the process involves three key elements working in tandem: oxygen, a specific light source, and a photosensitizer (PS) [16]. It is crucial that these components selectively affect the target cells without causing harm elsewhere. Specific light wavelengths cause the PS to initiate two different processes known as Type I and Type II reactions. Proteins, lipids, and nucleic acids are examples of biomolecules in the excited triplet state of the PS that undergo hydrogen atom exchange by radical processes in Type I pathways. This interaction generates free radicals and radical ions that subsequently react with oxygen, leading to the formation of reactive oxygen species (ROS). The type of radical produced varies depending on which biomolecule—whether proteins, lipids, or nucleic acids – is the target (Figure 2) [17–20].

In photodynamic therapy (PDT), the photosensitizer (PS) undergoes a series of processes upon absorbing light. Initially, it enters an excited singlet state and subsequently transitions to a triplet excited state through intersystem crossing. At this stage, the PS can proceed along two distinct pathways: it can directly interact with oxygen, transferring energy to produce singlet oxygen (Type II reaction), or it can engage with biomolecules through hydrogen atom (electron) transfer, leading to the formation of radicals that react with molecular oxygen to generate reactive oxygen species (ROS) (Type I reaction). Both singlet oxygen ($1O_2$) and ROS are highly reactive and short-lived.

Singlet oxygen, particularly crucial in PDT, is primarily produced through Type II reactions where the triplet excited state of the photosensitizer interacts with the triplet ground state of oxygen, a process known as triplet-triplet annihilation. This interaction results in the formation of singlet oxygen, which is highly reactive and potentially damaging [22].

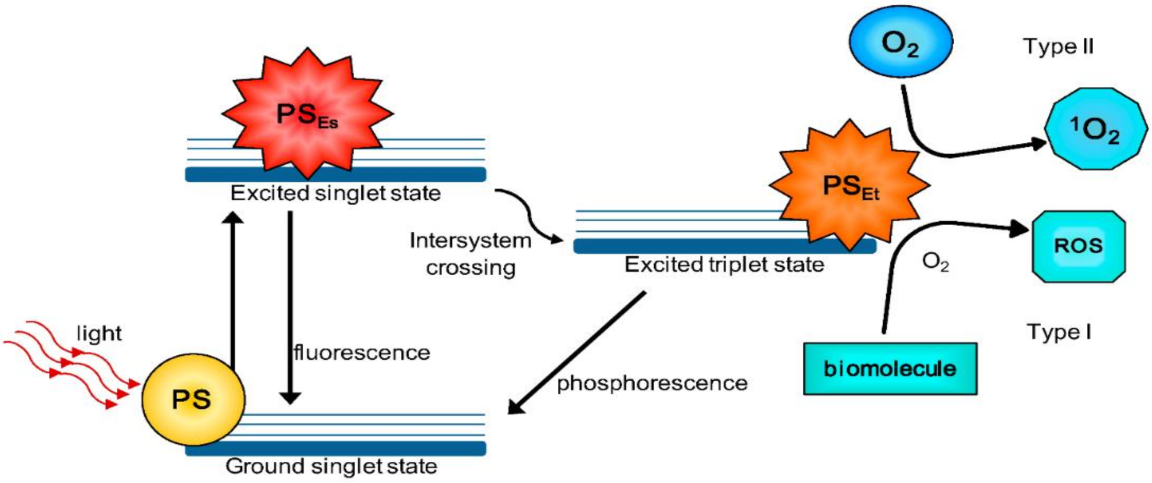

Figure 2. Mechanism of photodynamic therapy [21].

During PDT, both Type I and Type II reactions occur concurrently and are influenced by various factors including the specific photosensitizer used, oxygen and substrate concentrations, as well as the photosensitizer's affinity for the substrate. Given the short lifespan and high reactivity of singlet oxygen and ROS, their effects are localized within approximately 20 nanometers from where they are generated [23]. Therefore, precise localization of the photosensitizer is crucial in drug delivery studies aimed at targeting specific tissues, ensuring selective and localized sensitization.

Clinical PDT Against Cancer

Microbiological research led to the discovery of the photodynamic effect, but as antibiotics were available in the 1940s, its therapeutic application decreased. However, due to increasing microbial resistance to antibiotics, photodynamic therapy (PDT) has been reconsidered as an alternative treatment in recent decades [24].

Since its introduction into clinical use in the 1980s, photodynamic therapy (PDT) has been approved for treating various malignant and pre-malignant conditions [25, 26]. Cancers of the digestive system [27, 28], oesophagus [29, 30], head and neck [31], lung, cervix, bladder, non-melanoma skin cancer [32], and basal cell carcinoma are among them. Malignant pleural mesothelioma [33] is another type of cancer.

A typical PDT procedure in clinical practice involves three main elements: administering a specific drug dose, exposing the target area to light, and observing a designated drug-light interval. However, clinical outcomes can vary considerably, often due to factors, such as insufficient light penetration into the targeted tissue, development of drug resistance (especially in tumors), or variations in how patients metabolize the photosensitizer [34].

The "therapeutic window" typically spans wavelengths between 600 and 800 nm [35, 36]. Optimizing light delivery, such as using deeper wavelengths or employing techniques like interstitial light delivery instead of surface light delivery, can improve treatment efficacy [37–40].

Photosensitizers

Choosing the appropriate photosensitizer (PS) is critical for effective PDT treatment. The light used should fall within the therapeutic range (600–700 nm), allowing deeper tissue penetration and optimal activation of the PS. Moreover, the PS should be non-toxic to cells in the absence of light, ensuring it does not induce cell death. Additionally, it must exhibit selective absorption and retention by target cells. Additionally, its applications in laboratory settings, both in vitro and in vivo, are also considered.

Methylene Blue

Methylene Blue, derived from phenothiazine, is an organic dye known for its photosensitizing properties and vibrant colouration. This photosensitizer (PS) effectively eliminates cancerous cells (in vivo) and deactivates pathogens and viruses (in vitro) [41–43]. Its positively charged nature and low molecular weight facilitate enhanced interactions with both bacterial and human cells, making it highly suitable for photodynamic therapy (PDT) applications in treating infections and cancer. Methylene Blue is frequently utilized as a photosensitizer (PS) in antimicrobial PDT, targeting infections caused by Candida albicans, Enterococcus faecalis, and Escherichia coli. It is also gaining popularity as a PS in anticancer PDT, with several studies, including research conducted by our team, Tardivo et al., and Wagner et al., demonstrating encouraging outcomes [44].

Photo Gem (Hematoporphyrin Derivative, HpD)

The photo gem is called Hematoporphyrin Derivative, or HpD. Photo gem is a derivative of hematoporphyrin from Moscow, Russia. It is an animal-derived PS of the first generation. In terms of chemistry, photo physics, diagnostics, and treatments, it is identical to Photoprint. Its use for human consumption has been authorized by the Russian Federation’s Pharmacology State Committee as well as the Brazilian Health Surveillance Agency (ANVISA). Its absorbance spectra span from 500 to 630 nm, and its composition is a mixture of monomers and oligomers [45].

The primary side effect of photo gem, which is often taken systemically, is photosensitivity for a few weeks following delivery.

Curcumin

For ages, people have utilized curcumin, a polyphenolic molecule derived from Curcuma longa L., as a spice, medicinal, and colouring. It also functions as a PS. Numerous pharmacological uses for curcumin exist, including the treatment of liver diseases, wounds, blood purification, inflammation in the joints, and antibacterial qualities [46]. Curcumin’s extensive absorption of light between 300 and 500 nm (peaking at 430 nm) is accompanied by micromolar quantities of biological activity [47]. As a PS, it shows great promise in treating superficial infections that are localized and brought on by bacteria or fungi as well as superficial tumor particularly those that are cancerous of the skin and oral cavity [48, 49].

Phthalocyanines

Like porphyrins, phthalocyanines are considered second-generation photosensitizers (PSs) due to their outstanding photophysical and photochemical characteristics [50]. These include excellent stability under both light and chemical conditions, absorption of long-wavelength light with strong extinction coefficients, particularly between 650 and 750 nm, and effective generation of oxygen in singlet. Furthermore, they are synthesised using straightforward methods and can be easily modified to adjust their hydrophilicity [51].

Hybrid nanostructures, which integrate PSs with metal nanoparticles, are increasingly valued for their enhanced PDT capabilities in cancer treatment [52].

Hypericin

For decades, conventional medicine has made use of hypericin (HYP), a naturally occurring red pigment derived from Hypericum perforatum L. (St. John’s Wort) [53, 54]. Its varied therapeutic potential, including antidepressant benefits, as well as its effectiveness against cancer and viruses like HIV and hepatitis C, has been emphasized by recent biochemical investigations conducted over the past thirty years [55].

Because of its photochemical properties, such as its ability to target tumors, low production costs, and absorption of light near 590 nm (within the therapeutic window), HYP has attracted increasing interest as a photosensitizer (PS). It demonstrates minimal mutagenicity in the absence of light, shows little photobleaching, and has low toxicity. Its potential for use in PDT to treat malignancies has been highlighted by several in vitro and animal studies.

Due to its strong hydrophobicity, HYP dissolves in biological media, polar organic compounds, alkaline aqueous solutions, and organic bases. Unfortunately, its effective dispersion is limited by its insolubility in water and non-polar solvents [56], which lowers its photodynamic activity and makes its in vivo administration more difficult (Tables 1–2) [57–59].

NANOTECHNOLOGY / NANOPARTICLES AS COSMOCEUTICALS

Cosmeceuticals refer to cosmetic products containing biologically active ingredients with therapeutic benefits when applied topically. They are used primarily for enhancing appearance and are categorized between personal care items and pharmaceuticals [62]. Cosmeceutical products are recognized for their effective therapeutic benefits on skin, targeting issues like hair loss, wrinkles, photoaging, dryness, dark spots, uneven skin tone, and hyperpigmentation [63].

The personal care industry, particularly cosmetics, is experiencing significant growth, expected to expand rapidly. Nano-cosmeceuticals offer numerous advantages, including controlled release of active ingredients through mechanisms like polymer-drug interactions, formulation ratios, manufacturing processes, and physical or chemical interactions within components. These ingredients feature in hair care products, such as Identik Masque Floral Repair, Origem hair recycling shampoo, and Nirvel hair-loss control shampoo. They are formulated to prevent graying and treat hair loss. Nano-cosmeceuticals also improve the longevity of fragrances, such as Chanel’s Allure Parfum and Allure Eau Parfum spray.

These skincare formulations provide improved UV protection and enhance sunscreen effectiveness due to their nanoscale particle size, which increases surface area and facilitates better penetration of active ingredients into the skin. They also promote increased skin hydration and improved penetration capabilities. Compared to traditional cosmetics, skincare products featuring high entrapment efficiency, pleasing sensory attributes, and enhanced stability are preferred. Nanoparticles are widely utilized to deliver both hydrophilic and lipophilic drugs in products like whitening creams, anti-wrinkle serums, moisturizers, and hair restoration treatments, such as shampoos and conditioners (Figure 3) [64, 65].

CLASSIFICATION OF NANOCOSMECEUTICALS

Major Classes in nano cosmeceuticals: This area of the personal care sector is thought to be expanding at the quickest rate. A multitude of nano cosmeceuticals are integrated into skin, hair, and nail care products. The main kinds of nano cosmeceuticals are shown in Figure 4 and Table 3.

Skin Care

Cosmeceuticals in skincare products aim to enhance skin texture and function by preventing damage from free radicals and promoting collagen production. They support skin health by preserving the integrity of the keratin structure. Zinc oxide and titanium dioxide nanoparticles, known for their effectiveness in sunscreen creams, not only protect against UV rays but also help reduce oiliness, odor, and transparency [68, 69].

Moisturizing formulations often utilize SLNs, liposomes, niosomes, and nanoemulsions because they create a thin layer of humectants that retain moisture for extended periods. Commercialized anti-aging nano-cosmeceutical solutions, incorporating liposomes, nanospheres, nano capsules, and nanosomes, demonstrate potential for skin rejuvenation, firming, and lifting effect [70].

Table 1. Various photosensitizers and their modes of action, modes of administration, benefits, and drawbacks [60].

Photo Sensitizer	**Tissue Oriented or Vascular-Acting Photosensitizer**	**Optimum Dose (mg/kg)**	**Route of Administration**	**Advantages**	**Disadvantages**
Hematoporphyrin tissue	Tissue oriented	1.50.00	I.V.	_	Short medication-light interval (min): after three high-efficacy periods shown by imaging and PSA level decreases, no skin photosensitivity has been reported.
Porfimer-sodium	Tissue oriented	2.50	I.V.	Porfimer sodium prepared commercially is less variable than the original hematoporphyrin derivative.	Prolonged skin sensitivity: drug-light interval of days.
Temoporfin	Tissue oriented	0.15	I.V.	High quantum yield, meaning that a small amount of medication is needed to create a photodynamic effect.	Extended skin sensitivity lasting up to 6 weeks, a drug-light interval ranging from 3 to 5 days, and the occurrence of a rectourethral fistula in a patient post-radiotherapy.
Aminolevulinic acid-induced protoporphyrn IX	Tissue oriented	20.00	Oral	Preferential targeting of prostate cancer over normal tissue, with a short drug-light interval of 4 hours.	NA
Motexafin futetium	Vascular-functioning	2.00	I.V.	A brief interval between drug administration and light exposure (3 hours) without any reported skin sensitivity.	NA
Padoporfin	Vascular-functioning	2.00	I.V.	A minimal interval between medication and light exposure has shown no documented skin photosensitivity, with three effective periods demonstrated by imaging and reductions in PSA levels.	regular and extra prostatic treatment effect reported on MRI.

Table 2. Different sensitizers with examples [61].

Suggested Process	**Cell Line**	**Photosensitizer**
Drug efflux mediated by MDR	P388/ADR leukemia in mice.	A cationic PS is copper benzochlorin iminium salt.
ABCG2-related medication efflux	MX50 bronchoalveolar carcinoma, NCI-H1650.	• Phetrophorbide • E6 chlorin • PpIX derived from ALA (5-aminolevulinic acid)
TPPS2a's endocytic vesicle localization	NCI-H1650, MX50 bronchoalveolar carcinoma.	Meso-tetraphenylporphine disulfonated (TPPS2a).
Changes in mitochondrial size and function, as well as the uptake and/or subcellular distribution of the photosensitizer (PS)	Fibrosarcoma RIF-1.	• Phenotoporphyrin (PHP). • Zinc (II) pyridinium-substituted phthalocyanine (ZnPCP). • Photofrin II.
changes to the heme pathway's enzymes, which result in PpIX	Mammary adenocarcinoma in mice.	5. ALA, or 5-aminolevulinic acid.
Diminishment of light in tissue laser	glioma spheroids in humans.	5. ALA, or 5-aminolevulinic acid.
Apoptotic reaction that is delayed	Murine leukemia P388.	Amidine tin octaethylpurpurin (SnOPA).

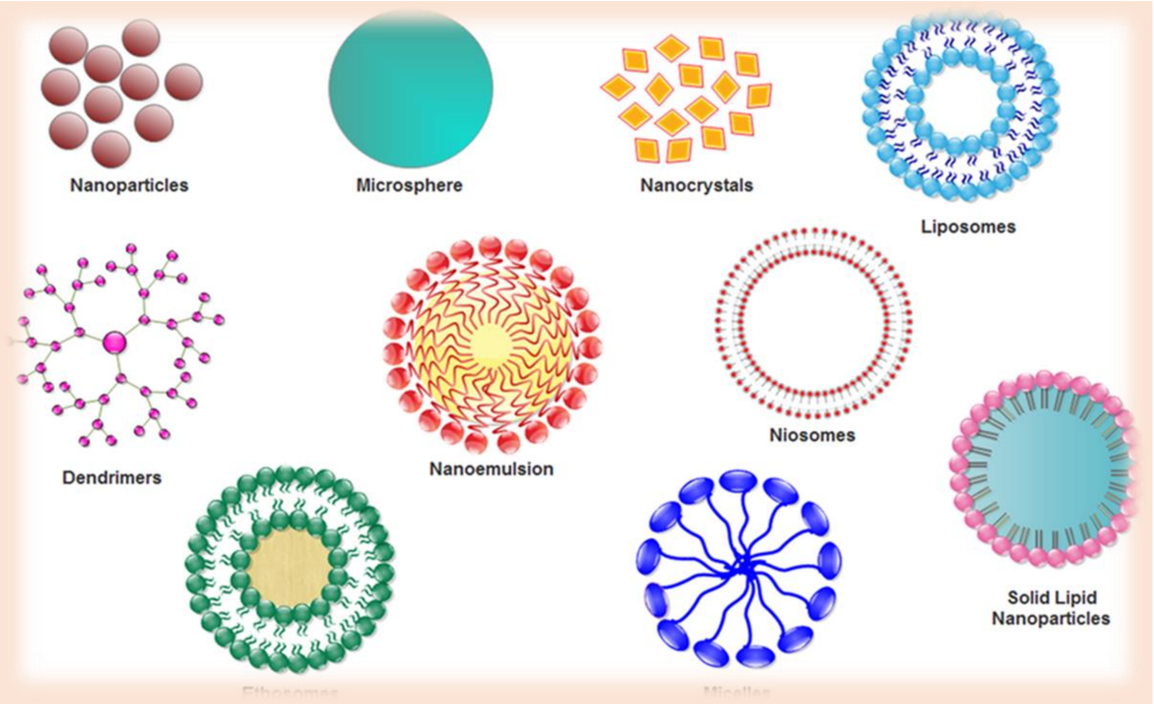

Figure 3. A visual representation of the several nano-carriers for cosmeceuticals [66].

Hair Care

Hair care products, such as conditioners, hair dyes, styling agents, and growth boosters target hair follicles and utilize nanoparticles of various sizes to enhance the delivery of active ingredients. Shampoos containing nanoparticles are designed to increase contact time with the scalp and hair follicles, forming a protective layer that aids in moisture retention within the hair shafts [71]. Nano-sized conditioning cosmeceuticals aim to enhance hair manageability, providing a glossy, shiny, silky, and soft appearance. Advanced delivery systems like liposomes, micro-emulsions, nano-emulsions, niosomes, and nanospheres are used to rejuvenate hair texture and shine, repair damaged cuticles, and reduce brittleness and oiliness [72].

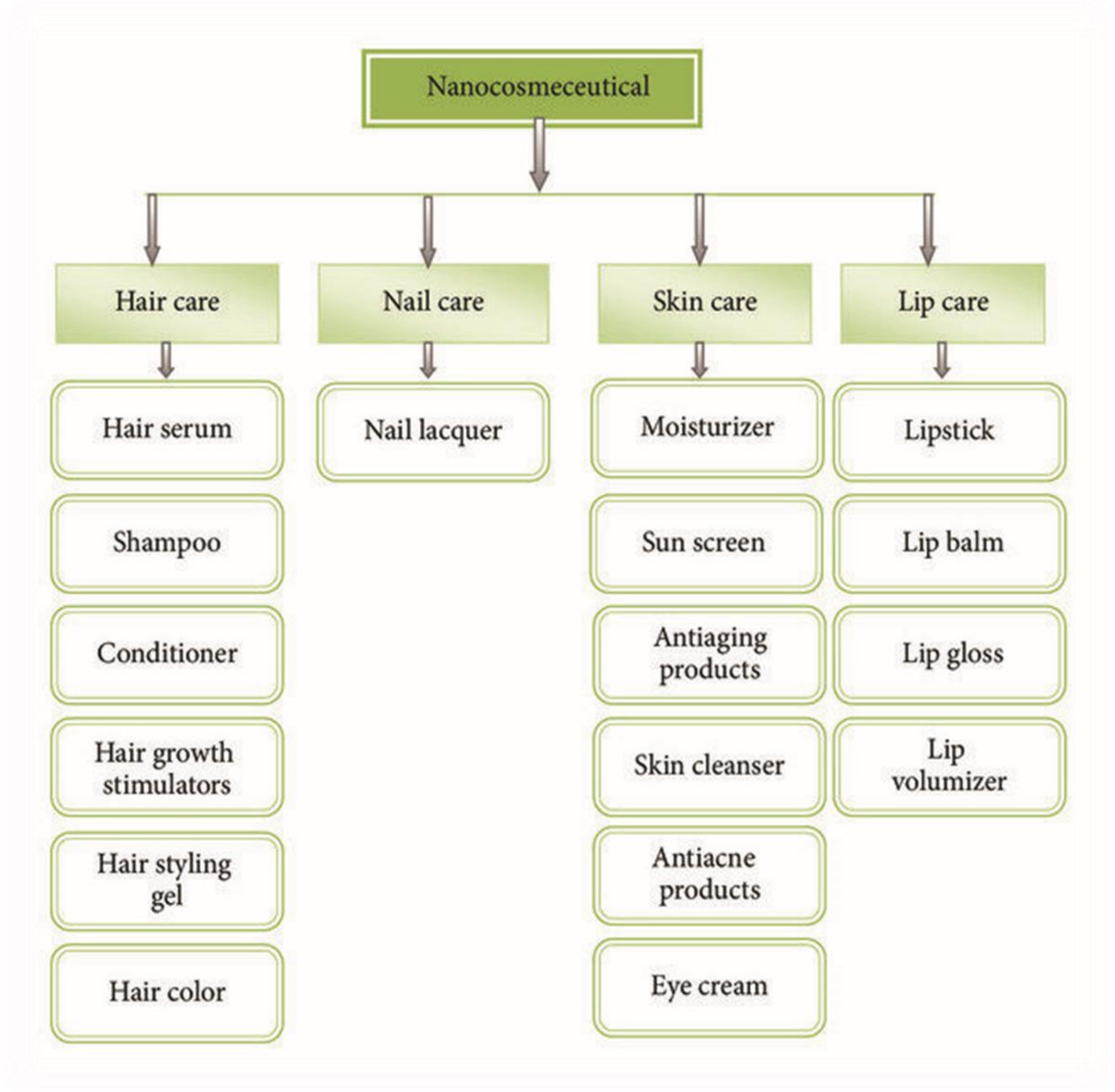

Figure 4. Major classes in nanocosmoceuticals [67].

Lip Care

Nano cosmeceutical lip care products encompass lipstick, lip balm, lip gloss, and lip volumizers. These products utilize a range of nanoparticles in lipsticks and lip gloss to enhance lip softness by reducing transepidermal water loss [73]. They also aid in maintaining long-lasting colour retention by preventing pigment migration from the lips.

Lip volumizers based on liposomes enhance lip volume, moisturize, define, and smooth lip contour wrinkles [74].

Nail Care

Nanotechnology-driven advancements in nail care offer significant benefits over traditional methods. Nano cosmeceutical nail products, such as nail paints, deliver enhanced durability, quicker drying times, longer lifespan, improved chip resistance, and a wider range of colours, making application easier and more versatile [75].

Innovative strategies include incorporating silver and metal oxide nanoparticles into nail paints to create antifungal treatments for toenail infections caused by fungi [76].

Table 3. Marketed Formulations of Nano Cosmeceuticals [77].

Product Name	**Brand Name**	**Purpose**	**Formulation**
Capture Totale	**DIOR**	"Reduces wrinkles and dark spots while enhancing skin brightness with added sunscreen protection".	LIPOSOME
Dermo-some	**MICROFLUIDICS**	"Moisturiser".	LIPOSOME
Decorte's Liposome Facial Cream for Moisturizing	**DECORTE**	"Moisturiser".	LIPOSOME
Liposomal Natural Progesterone for Skin Cream	**Now/solutions**	"Maintaining a healthy feminine balance".	LIPOSOME
Fill Derma Lips Lip Volumizer.	**SESDERMA**	"Increases lip volume, contours wrinkles, hydrates skin, and outlines lips".	
Niosome+ Mastered age therapy.	**Lancôme**	"Removes wrinkles".	NIOSOME
Niosome+	**Lancôme**	"Foundation cream, clear and white skin tone".	NIOSOME
Anti-Aging99 Response^{0}Cream^0	**Simply Man Match**	"Treatment of Wrinkles".	NIOSOME
Identik Masque Floral Repair	**Identik**	"Hair repair masque".	NIOSOME
Eusu Niosomes Makam Pom Whitening Facial Cream	**Eusu**	"Skin Whitening".	NIOSOME
Allure Body Cream**	**Chanel**	"Body moisturizer".	SLN
Allure Parfum Bottle*	**Chanel**	"Perfume".	SLN
Allure Eau Parfum*Spray.	**Chanel**	"Perfume".	SLN

NANOTECHNOLOGY FOR VETERINARY SCIENCE

In the twenty-first century, nanotechnology is poised to bring significant advancements to clinical veterinary medicine, potentially revolutionizing veterinarian care, animal welfare, and various aspects of the animal industry [78]. Veterinary nanotechnology encompasses a broad spectrum of applications, including enhancing diagnostic tools and treatment delivery systems, developing molecular and cellular breeding technologies, monitoring animal health throughout their lifecycle, managing livestock waste, and detecting pathogens [79].

Nanotechnology enables the creation of molecular and cellular nanodevices, detection of contaminants, production of nano-scale medications, and implementation of controlled drug delivery systems [80]. Beyond its impact on veterinary care and animal production industries, nanotechnology holds promise in combatting diseases by enabling precise delivery of medications to specific cell types via nanoparticles designed to target damaged cells directly (Table 4) [81].

NANOVACCINES

Nano vaccines represent an innovative approach to immunization that is gaining traction. These vaccines offer enhanced effectiveness compared to traditional ones by triggering both humoral and cell-mediated immune responses. They harness the body's immune system to target bacteria, thereby preventing infections and diseases [82, 23]. Modern vaccination methods have evolved from using live or inactivated organisms to safer alternatives incorporating synthetic and recombinant DNA. Many new vaccine candidates exhibit low immunogenicity and are prone to degradation, necessitating the addition of well-prepared adjuvants to enhance efficacy [84].

Traditional adjuvants are fixed in their properties, prompting the development of novel antigen-carrying techniques through nanotechnology. Nanoparticle-based adjuvants can be customized to elicit precise immune responses with fewer doses and easier administration routes, like intranasal delivery to boost mucosal immunity. This versatility is especially beneficial in veterinary contexts, where widespread immunization of animals is routine or where traditional methods face challenges from intricate management systems or logistical limitations [85].

Table 4. Marketed formulations of nanoparticles used in veterinary science [85].

S. N.	**Carriers of Nanoscale**	**Medical/Veterinary Applications**	**Animal Species Undergoing Trial/Evaluation/Approval**
1.	“Magnetic nanoparticles”	MRI$^{\$}$ contrast and medication$^{@}$ delivery (Kim et al., 2010).	Cats (Underwood et al., 2012)
2.	“Gold nanoparticles”	In-vitro$ diagnostics (Kim et al., 2010).	_
3.	“Quantum Dot”	Fluorescent contrast, in vitro diagnostics* (Kim et al., 2010).	_
4.	“Dentrimers”	Microbicides: and vaccine delivery (Kim et al., 2010).	Pigs (Underwood^ et al., 2012).
5.	“Micelle”	Therapeutics.	Sheep, birds, horses (Underwood? et al., 2012).
6.	“Liposomes”	Therapeutics.	Cattle, dog, horse, cat, bird, and sheep (Underwood et al., 2012).
7.	“Nano emulsions”	Drug. delivery and therapeutics. **	Dogs and cats (Underwood et al., 2012).
8.	“Nanosphere”	Vaccine delivery.	Horse/ (Underwood/ et al., 2012).

Animal Breeding and Reproduction

Dairy and hog farmers encounter significant expenses, and time demands in managing breeding activities [86]. Emerging nanotechnology in animal reproduction aims to alleviate these challenges by developing nano-biosensors capable of monitoring reproductive status through physiological changes [87]. Additionally, it seeks to characterize gamete cells at the nanoscale using advanced microscopy techniques like atomic force microscopy and similar scanning methods.

Research in nanotechnology for animal reproduction also focuses on creating systems for sustained release of substances, such as hormones, vitamins, antibiotics, antioxidants, and nucleic acids [88, 89]. It includes developing chemical processes to synthesize metal nanoparticles for applications in fertility control, as well as designing nanodevices for safe cryopreservation of gametes and embryos [90].

MECHANISM

One innovative approach under investigation involves implanting a nanotube beneath the skin to monitor changes in blood estradiol levels in real-time. Nanotubes can track animals by binding to estradiol antibodies during estrus using near-infrared fluorescence [91]. The sensor’s signal is integrated into a centralized breeding monitoring and control system for activation [92].

Nanotechnology methodologies, such as microfluidics, nanoparticles, and bioanalytical nano-sensors are poised to unravel new insights into animal health, growth, reproduction, and disease prevention and treatment [93]. Microfluidic and nanofluidic processes represent modern techniques that enhance the development of in vitro embryos and traditional fertilization methods [94]. Recent studies have demonstrated microfluidics’ capability to isolate motile sperm effectively without requiring centrifugation [95].

DISEASE DIAGNOSTIC

Veterinary diagnostics for chronic diseases often entail lengthy delays, sometimes spanning days, weeks, or even months, before outward symptoms appear. By this time, infections can spread extensively, sometimes necessitating herd culling. Nanotechnology operates on a scale comparable to viruses and other disease-causing agents, enabling early detection and intervention. Therefore, nanotechnology holds promise as a critical tool for precise clinical diagnosis [96].

The concept of One Health advocates for leveraging nanotechnology tools to investigate animal diseases and utilize animal models for diagnosing human ailments. Current research explores the use of quantum dots for in vivo imaging in microscopic animal models [97].

MECHANISM

In contrast to computed tomography (CT) and magnetic resonance imaging (MRI), which mainly give anatomical data, nuclear medicine imaging methods, such as single photon emission computed tomography (SPECT) and positron emission tomography (PET) provide functional and metabolic data. However, the integration of PET and SPECT scans with MRI and CT scans offers comprehensive information on both anatomy and metabolism [98, 99].

To manage disease progression earlier than traditional morphological imaging methods or laboratory tests detect, non-invasive, targeted molecular imaging modalities are essential. These modalities provide in vivo anatomical and physiological information by tracing the physiological distribution of radiopharmaceuticals (positron and gamma emitters) in patients, visualizable using SPECT or PET scanners in nuclear medicine [100, 101].

NANOTECHNOLOGY AS DENTISTRY TOOL

Nanomaterials differ from larger particles of the same composition primarily due to their significantly higher reactivity stemming from a much larger surface area relative to their volume (volume-specific surface area). They can be readily absorbed by the body, particularly through the skin, lungs, and digestive tract, and prolonged exposure may lead to their accumulation primarily in the digestive system and lungs. Potential consequences include inflammation, cellular damage, and alterations in DNA. The implications of these findings in dentistry remain unclear.

Nanoparticles are deliberately incorporated into dental products to enhance their performance. While few items are specifically engineered to release these particles, they find use in various sectors beyond orthodontics, such as intraoral scan sprays and CAD/CAM design and manufacturing. It is estimated that approximately 3500 dental materials incorporate some form of nanoparticles (Figure 5) [102].

A relatively new area known as nano-dentistry has grown in prominence in recent years, combining the efforts of numerous scientists and medical professionals to create novel materials. Nano-dentistry [103, 104] is the study of detecting, treating, and preventing oral and dental illnesses using nanostructured materials and technologies. Common objectives include enhancing patient oral health, reducing therapy invasiveness, and raising patient cooperation with physicians [105]. Orthodontics, endodontics, conservative medicine, anesthesiology, and aesthetics are the most engaged disciplines. Tissue engineering and nanorobotics in dentistry have received a lot of attention in recent years, as has stem cell research for cartilage regeneration and bone augmentation [106–109].

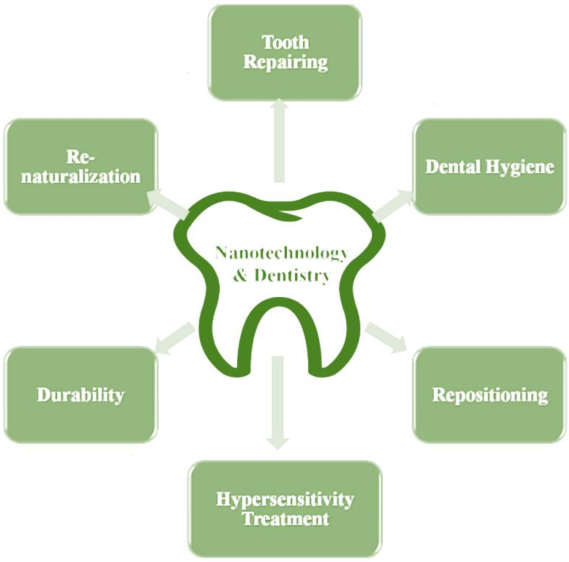

Figure 5. Nanotechnology as dentistry tool [103].

Orthodontic Bands

Dental bands are commonly employed in fixed orthodontic treatments due to their integral role in the orthodontic system's function. However, their use in the posterior dental regions, which are challenging to clean, can contribute to the retention of bacterial plaque. Persistent plaque accumulation around orthodontic brackets and bands has been linked to a rapid shift in bacterial composition, promoting the growth of acidogenic bacteria like Lactobacilli and Streptococcus mutans. This increases the susceptibility to cavities, white spot lesions, and enamel demineralization (Figure 6) [110].

MECHANISM

Recent advancements in dental technology allow for the incorporation of antibacterial agents into dental resins and cements, aimed at reducing cavities and preventing white spot lesions while maintaining strong adhesion. Substances like fluorides, zinc oxide, and chlorhexidine have proven effective in mitigating the acidic oral environment and bacterial activity.

Antimicrobial components, such as silver nanoparticles, are now utilized in band cements to prevent the formation of white spots. Studies have shown that these resins exhibit mechanical properties comparable to standard controls and are generally biocompatible. However, additional research is needed to fully establish their efficacy in the oral environment, particularly over the course of orthodontic treatment [111].

Figure 6. Orthodontic bands [112].

Orthodontic Mini Screws

Controlling the anchoring during tooth movement is an important aspect of good orthodontic therapy. With anchoring control and force system establishment, the main objectives of orthodontic therapy are to reduce undesired movements while maintaining the desired impact.

Temporary anchoring devices (TADs), such as minis crews, mini plates, and implants, have been used for orthodontic purposes in various year [113]. When used as an independent anchorage, they are inserted into the bone to increase orthodontic anchorage, either directly or indirectly, by supporting and strengthening the anchor teeth.

Temporary anchorage devices (TADs) achieve stability primarily through mechanical means rather than relying on osseointegration (biomechanical). While mini plates demonstrate a higher success rate, orthodontists often prefer mini screws due to their cost-effectiveness, ease of insertion and removal, and availability in various sizes. Unlike mini plates that require surgery by an oral surgeon, TAD placement is less invasive and more affordable, making it accessible for treatment by trained orthodontists [114–118].

The literature describes multiple insertion sites for TADs in both the maxilla and mandible, including locations, such as the vestibular bone, zygomatic buttress, interradicular spaces, symphysis[117-118], and even the hard palate [119–121].

Therefore, to provide extra stability and resistance to orthodontic forces, it is essential that the bone and Mini screw surface be particularly close to one another. In addition, early screw loss may be facilitated by inflammatory pathways that impact primary stability [122, 123]. Titanium dioxide (TiO2) nanotube arrays on the studied surface were a distinguishing feature of the two investigations that tested the stability and osseointegrations of nanotechnology-modified mini screws surfaces (Figure 7).

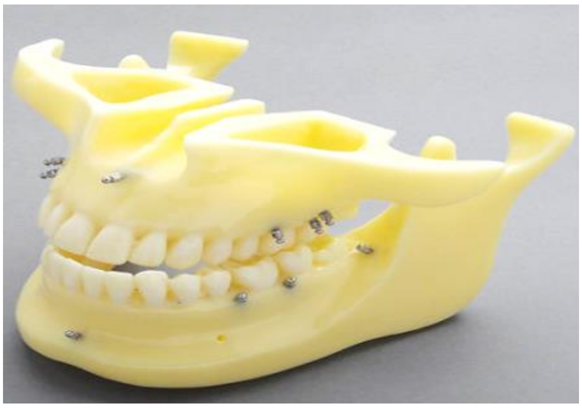

Figure 7. Orthodontic mini screws [124].

Orthodontic Power Chains

Since their inception in the late 1960s, power chains have become a standard component in orthodontic practices. They are typically made from polymeric materials, such as polyesters or polyether, manufactured through the process of polymerization. They provide several therapeutic benefits, including influence the degree of persistent deformation and the strength of orthodontic power chains.

Mechanism being reasonably priced, easily adjustable to fit the needs of each patient, and producing gentle, continuous pressures. Their great degree of flexibility helps to improve space closure in extraction scenarios. However, power chains also have drawbacks. It has been established beyond dispute that their mechanical efficacy wears down with time, necessitating regular replacement. Both internal and external factors.

Furthermore, they are hydrophilic and discolour over time, making them unsuitable for maintaining dental health [125]. They also absorb liquids from the oral cavity.

In their Taiwanese work, Cheng et al. attempted to use a surface treatment known as nanoimprinting to enhance the physical properties of power lines. The process creates what are known as nanopillars – small, uneven structures on the chains' surface. This process changes the material's hydrophilic to hydrophobic properties, which seems to be a promising solution that mitigates the shortcomings of these orthodontic auxiliaries (Figure 8) [126].

Figure 8. Orthodontic power chains [127].

NANOTECHNOLOGY IN THE MEDICAL FIELD AS NANOBIOTECHNOLOGY

Utilizing nanobiotechnology. Nanobiotechnology is biotechnology at the nanoscale, as it involves the development and application of nanotechnology tools to study biological systems. It is the term used to characterize the combination of biology and nanotechnology. Nanoparticles, for example, can be utilized in biological systems as probes, sensors, or biomolecule delivery systems [128].

Nanomedicine

Drug delivery systems, medical diagnostics, nanoimaging, chemotherapy analytical tools, nanodevices, and nanomedicine are the five primary sub-disciplines that comprise this relatively young field of medical research. One may say that the potential advantages of nanobiotechnologies provide considerable promise for gene therapy, diabetes, cancer treatments, antiviral and antifungal medications, and chronic lung ailments. Photodynamic treatment is one surgical use of nanomedicine that may be used in addition to medicine [129].

Nanomedicine for Diagnosis

Nanotechnologies may assist medical personnel with single-cell and molecular diagnosis. Silver, gold, and quantum dot nanoparticles are among the most widely used nanoparticles. However, a variety of other nanotechnological instruments, including as nano biosensors, are helpful for controlling matter at the nanoscale and may have applications in medicine. Furthermore, nanotechnologies will allow for point-of-care diagnostics, the integration of diagnostics and therapeutics, and the progress of customized medicine, pushing the limits of present molecular diagnostics. Although there are no limits to future diagnostic applications, biomarker identification, early cancer diagnosis, and infectious germ detection are expected to have the most current applications.

Nano-Pharmacology for Nano-Therapy

Treatment is an essential element of medicine. Therapy for an existing issue is sought, even if illness prevention is preferred over treatment. The main goal of treatment, whether symptomatic or targeted, is to relieve the patient’s suffering. For millennia, there has been an unwavering emphasis on treatment growth. The advent of nano therapy into the sphere of medical treatment has provided a new hope in medicine.

Nano-Surgery

Nano-surgery is a new concept in surgical medicine. Because a small surgical incision leads to less blood loss and fewer intraoperative and postoperative problems, it is widely accepted that a small wound is the ideal outcome of modern surgery. Furthermore, a small wound shortens the patient’s hospital stays after surgery. Consider the developments in eye surgery. Near-infrared lasers may generate femtosecond laser pulses based on multiphoton phenomena. These laser pulses can be utilized for imaging as well as creating sub-micron laser effects that do not damage the surrounding tissue. According to published study, fluorescently tagged intracellular structures of living cells underwent a range of imaging and nano surgical operations utilizing near-infrared femtosecond laser pulses. Nano-surgery was revealed to be capable of achieving sub-micrometre precision while preserving the cell’s integrity.

CONCLUSIONS

The integration of nanotechnology into a variety of sectors, including dentistry, veterinary care, pharmacy, and cosmeceuticals, has ushered in a new era of innovation and advancement. Nanoparticles have altered drug delivery strategies due to their unique properties that improve therapeutic efficacy while minimizing side effects. Nanotechnology has enabled personalized drug delivery systems in pharmacies by increasing bioavailability and reducing dosing frequency. Nanocosmeceuticals, such skincare, haircare, lip care, and nail care products, have transformed the industry by increasing penetration and stability. Nanotechnology offers enormous potential in veterinary research for improving animal health and welfare through improved diagnostics, therapy delivery, and disease management. Additional research is needed to fully comprehend the long-term consequences of using nanoparticles into dentistry items, despite its potential for improving oral health treatments. Nanobiotechnology, which combines biology with nanotechnology, is an effective technique for exploring biological phenomena and developing novel therapies. In terms of science and medicine, nanotechnology has transformed the game by opening previously unimaginable avenues for innovation and improving the health of both people and animals.

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