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Review Article

Microneedling Drug Delivery System: Strategies, Design, Manufacturing, Clinical Aspects and Treatment for Cancer Therapy

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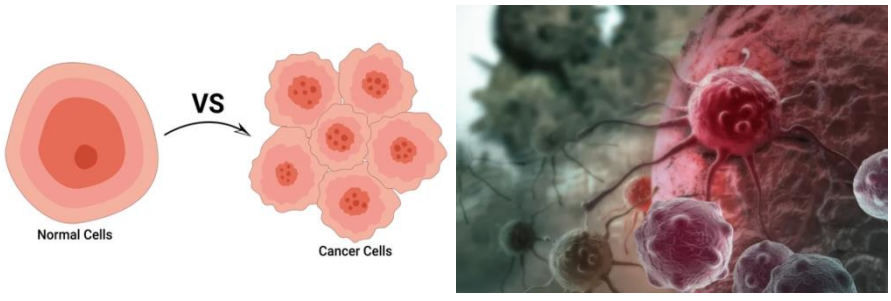
Abstract

Microneedling, a minimally invasive technique traditionally used in dermatology, has emerged as a promising approach to cancer therapy. The procedure involves creating microchannels in the skin using fine needles, enhancing the delivery of therapeutic agents directly into tumor tissues. This method overcomes the limitations of conventional cancer treatments, such as systemic toxicity and poor drug penetration, by facilitating localized and controlled drug delivery. Microneedling can also stimulate immune responses and induce tissue regeneration, potentially enhancing the effectiveness of immunotherapy and promoting tumor suppression. Recent studies have shown that microneedling can be combined with nanoparticles, chemotherapeutics, or gene therapies, allowing for a more precise and targeted treatment of cancer cells while minimizing damage to healthy tissues. Additionally, microneedling-based drug delivery systems can improve the bioavailability of drugs, reducing required dosages and associated side effects. The technique has been instrumental in treating skin cancers, such as melanoma, but its potential application in other solid tumors is currently being explored. While promising, further clinical studies are needed to optimize microneedling parameters and evaluate its long-term safety and efficacy in cancer therapy. As the field progresses, microneedling may revolutionize the delivery of cancer therapeutics, offering a cost-effective, patient-friendly option that complements existing treatments.

Keywords: Microneedling, Cancer therapy, Nanoparticles, Immunotherapy.

Introduction

Changes in cell metabolism can play a role in transformation and cancer progression. These metabolic profiles can also image tumors, offer predictive insights, and treat cancer. Therefore, understanding cancer metabolism is crucial for grasping basic cancer pathophysiology and has significant implications for clinical oncology.[1] Human cancers are incredibly diverse, with over 200 distinct types, each differing based on their normal cell origins, acquired somatic mutations, altered transcriptional networks, and the influence of local tissue environments. Efforts have been made to simplify this complexity into a set of fundamental principles known as cancer hallmarks. Despite major advances in cancer research, diagnosis, and treatment, most patients with advanced metastatic cancer face a terminal illness that remains incurable with current therapies. Approximately 90% of cancer-related deaths are due to metastatic disease rather than primary tumors.[2,3,4]



(a) (b)

Figure 1 (a): Difference in Normal Cells & Cancer Cells (b): Microscopic View of Cancer Cell Proliferation. [2,3]

Microneedles technology is an innovative transdermal therapy that involves a patch embedded with tiny, micron-sized needles. These needles are designed to deliver vaccines, drug molecules, proteins, genes, antibodies, nanoparticles, and more. This approach effectively addresses the limitations of traditional cancer treatments, offering a painless experience for patients.[5] Microneedles are advantageous throughout the entire process, from diagnosis to treatment, and even in theragnostic applications. Microneedles are self-operating tools that extract interstitial fluid transdermally and, simultaneously, deliver drugs, vaccines, and other therapies in a minimally invasive, painless process.[6,7]

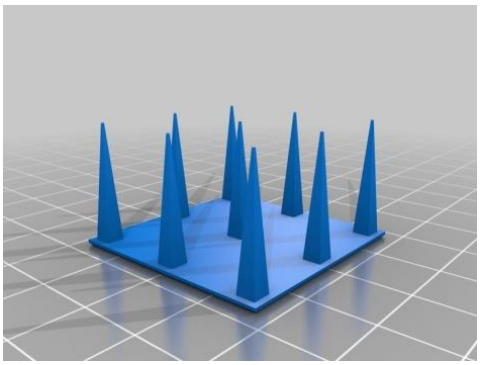


Figure 2: Microscopic view of Microneedles. [6,7]

General Attributes of MNs[8]

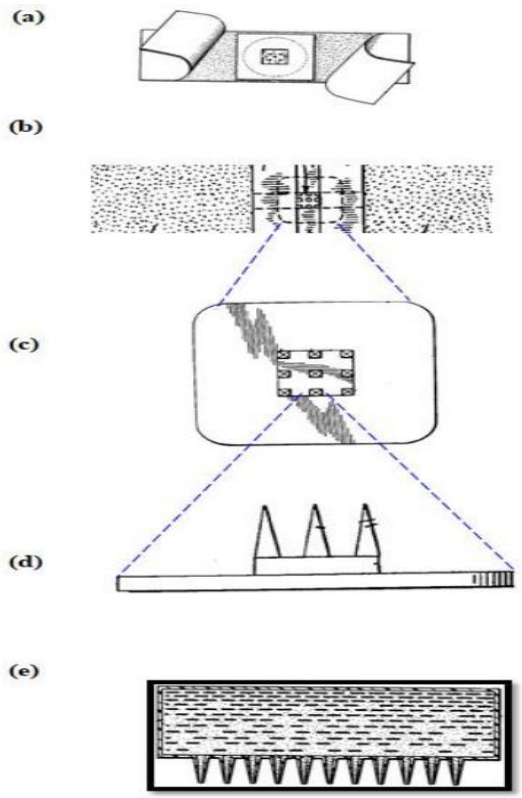


Figure 3: History of Microneedles (MNs)

(a) Plan view of the microneedle device,

(b-d) Plan view of microneedle device, substantially to scale, blown-up to show the MNs, (e) MNs patented by Alza Corporation. [8]

Strategies for Drug Delivery

Protein medications can be applied to different cancer growth medicines, inoculations, and treatment of hereditary infections. Quick advancement is normal; be that as it may, drug conveyance is restricted because of the issues of low soundness and ingestion. For instance, during dosing and stockpiling, protein denaturation, drug retention efficiency, and cell porousness related to sub-atomic size can prompt restricted restorative efficiency. Microneedle research is being directed at working on the conveyance efficiency of protein drugs. For instance, microneedle innovation has been produced for proteins including insulin, desmopressin, erythropoietin, lysozyme, glucagon, glucagon-like peptide-1, parathyroid chemical, and development chemical. The determination of materials and plans for protecting protein drug solidness remains a difficult task, particularly in enormous scope stockpiling arranging, and creation chains for clinical use. Detailed a microneedle with glucose reaction and temperature strength that was created utilizing phenylboronic corrosive for insulin drug conveyance in diabetes treatment. [9,10]

Microneedles Material and Methods of Manufacturing

Going now to MN producing strategies, the most regular techniques for manufacturing include solvent casting, micro-molding, pulling pipettes, etching, lithography, ceramic sintering, laser cutting/ablation, electropolishing, and micro stereolithography.[11] Different natural and inorganic materials are utilized in creating MNs of various designs and shapes. Concerning the materials utilized in manufacturing MNs, Guillot, and partners distinguished different materials and techniques utilized in the manufacture of MNs, and they additionally gave the benefits and detriments of the separate techniques.[12] Regeron Inc., a Korean-based organization, revealed dissolvable MNs of intensity shock protein (HSP90a or potentially its parts) which were ready according to the techniques depicted by Moga and associates.[13] Designers Ronnander and Simon of LTS Lohman and New Jersey Establishment of Innovation fostered a polyvinyl pyrrolidone (PVP) MNs exhibit fix for conveying macromolecular mixtures, for example, sumatriptan or its succinate salt (utilized for headache) by microporation of the skin. Also, the PVP MNs exhibit organization includes glycerol which is demonstrated as a humectant/conditioner, and polysorbate 80 goes about as a surfactant.[14] The fix of MN exhibit helps in the conveyance of said macromolecules utilizing an ongoing source that is controllable. In any case, on a couple of events, MNs couldn't accomplish a productive helpful impact.[15] Such issues were contemplated and fixed by Wang and partners utilizing polymeric MNs that are gotten utilizing polyvinyl liquor and maltose. Such a mix of polymers not only assisted in that frame of mind with great mechanical strength yet in addition MNs that can enter through the layers of skin to produce micropores.[16]

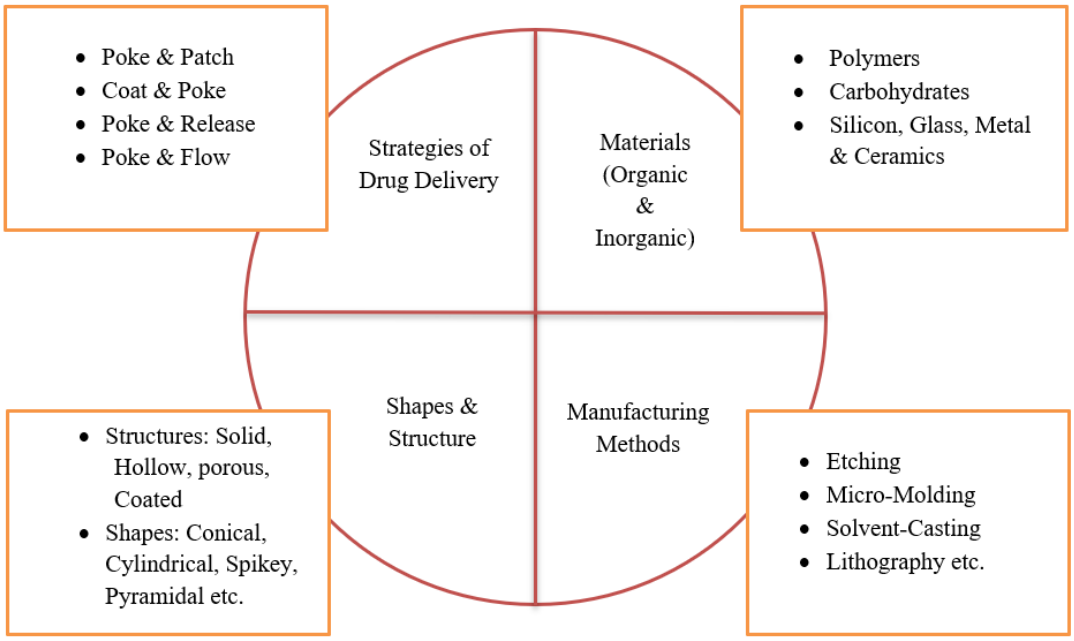


Figure 4: Schematic representation of general attributes of MNs.

Design and Geometry of MNs

When designing microneedles (MN) for optimal performance, considerations such as skin penetration depth, pain minimization, and achieving the intended objective must be taken into account. Parameters such as MN dimensions and geometry play a crucial role in determining the efficacy of MNs. The dimension and geometry of MNs, including tip diameter, aspect ratio, height, and needle density, affect their functionality.[17] Tip diameter influences the force required for skin penetration; smaller tip diameters require less force but do not affect penetration depth. Aspect ratio, the ratio of height to base width, affects insertion ease and mechanical strength. Increasing the aspect ratio facilitates skin penetration but also increases failure force while decreasing it enhances mechanical strength. MN height must be optimized for penetration depth without causing pain or bleeding. The material composition also influences penetration depth.[18]

MN design parameters such as tip diameter, aspect ratio, height, and density significantly impact their functionality and efficacy. Careful consideration and optimization of these parameters are essential to ensure optimal performance, delivery of active ingredients, and minimal discomfort for the subject. Achieving an optimal balance between skin penetration depth, pain minimization, and intended objective is crucial in designing effective MNs. Geometric factors play a crucial role in enhancing the performance of microneedles (MNs) by improving skin penetration, mechanical strength, delivery efficiency, and tissue adhesion. [19] Different geometric designs have been developed to achieve these goals. Conical and pyramidal MNs have been traditionally used, with pyramidal MNs demonstrating higher mechanical strength due to their larger cross-sectional area. Novel designs like "Tanto-blade" inspired MNs with beveled tips and "I-beam" geometry have also been explored for better penetration and shear strength. The mechanical strength of MNs is not only influenced by their geometry but also by the materials and cargo loaded into them. Studies have shown that incorporating certain microparticles can enhance mechanical strength, while others can weaken it due to poor adhesion.

These designs improve drug efficacy by increasing tissue adhesion, preventing premature removal of MNs. However, achieving consistent skin penetration depth with MNs remains challenging due to variations in human skin composition, condition, and thickness.[20] Customizable MNs may offer a potential solution to tailor skin penetration depth for individual differences, thereby maximizing the efficacy and reliability of biosensing and drug delivery applications.[21]

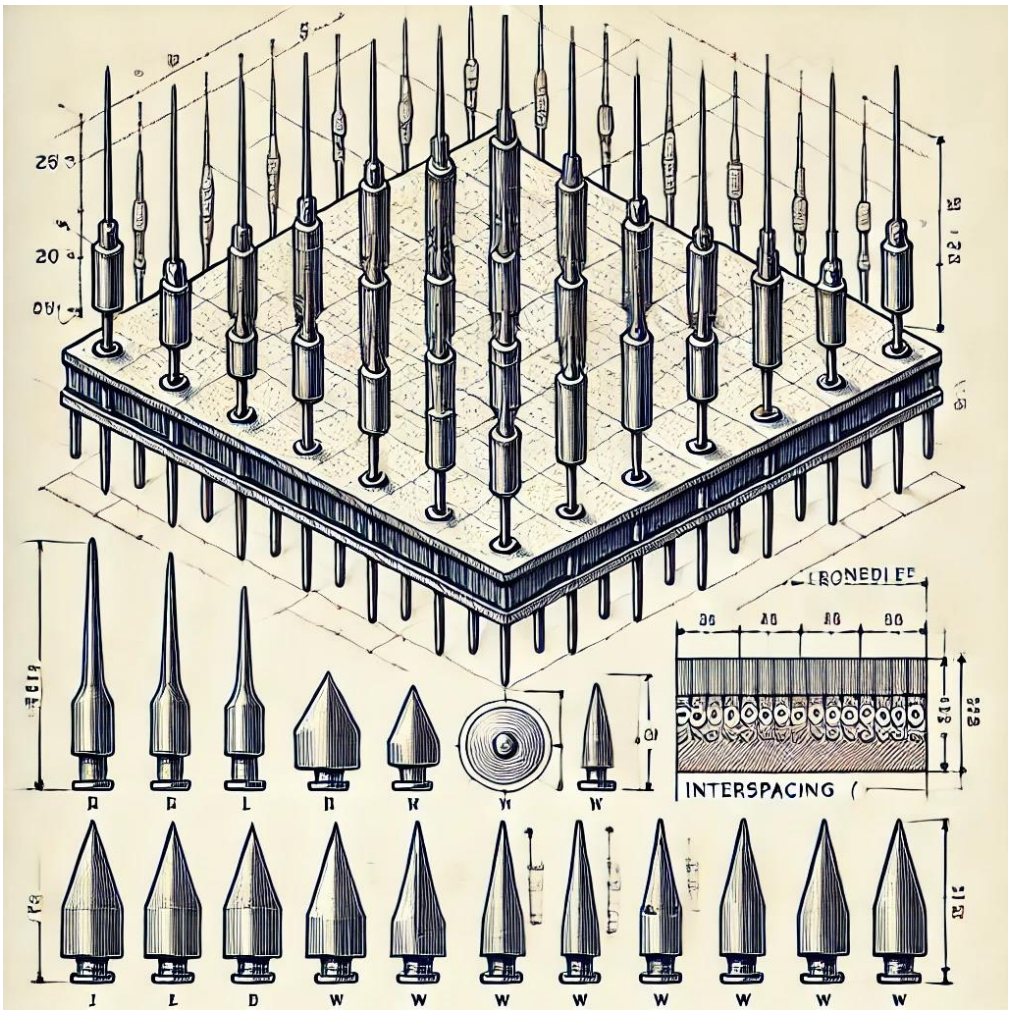


Figure 5: Design and geometry of MNs

(a) Illustration of geometrical parameters in a microneedle array

(b) Geometry of MNs length (L), thickness (T) and width (W)

(c) Different shapes of MNs (i) Rectangular microneedle with a sharp edge (ii) cylindrical (iii) conical (iv) tapered (v) arrow headed.[21]

Different Cancer Treatments Using MNs

MNs help in beating the impediments related to customary medication conveyance frameworks. They have been effectively assessed for the conveyance of little atoms, and enormous particles, like chemotherapeutic specialists, proteins, and hereditary material. MNs additionally help in conveying microparticles or on the other hand nanoparticles of anticancerous drug substances.[22] In the accompanying segments, we examine MNs that work given sensor innovation, MNs that are utilized for therapy of bosom malignant growth, and skin carcinoma, and lastly the 3D printed MNs for therapy of disease.[23]

MNs Based on Sensor Technology

Reconciliation of MNs with microelectronic sensors is an emerging area. The sensor-based MNs can change over non-electrical sources of info like temperature or tension from its general climate to microcomputer coherent electrical signs. Customarily, blood tests are utilized/ removed from subjects to quantify the grouping of the analyte. As of now, the 'point-test' approach is utilized, wherein blood is gathered as a drop onto a test strip and followed by embedding into an electronic gadget to show the outcome on the presentation screen.[24,25] One substitute to conquer the above restriction is the utilization of sensor-based MNs, which cause no or less aggravation contrasted with hypodermic needles, harmless, safe, and simple to utilize. For the most part, there are four distinct sorts of microneedle-based sensors and their standards of working are delineated in Figure 6.[26]

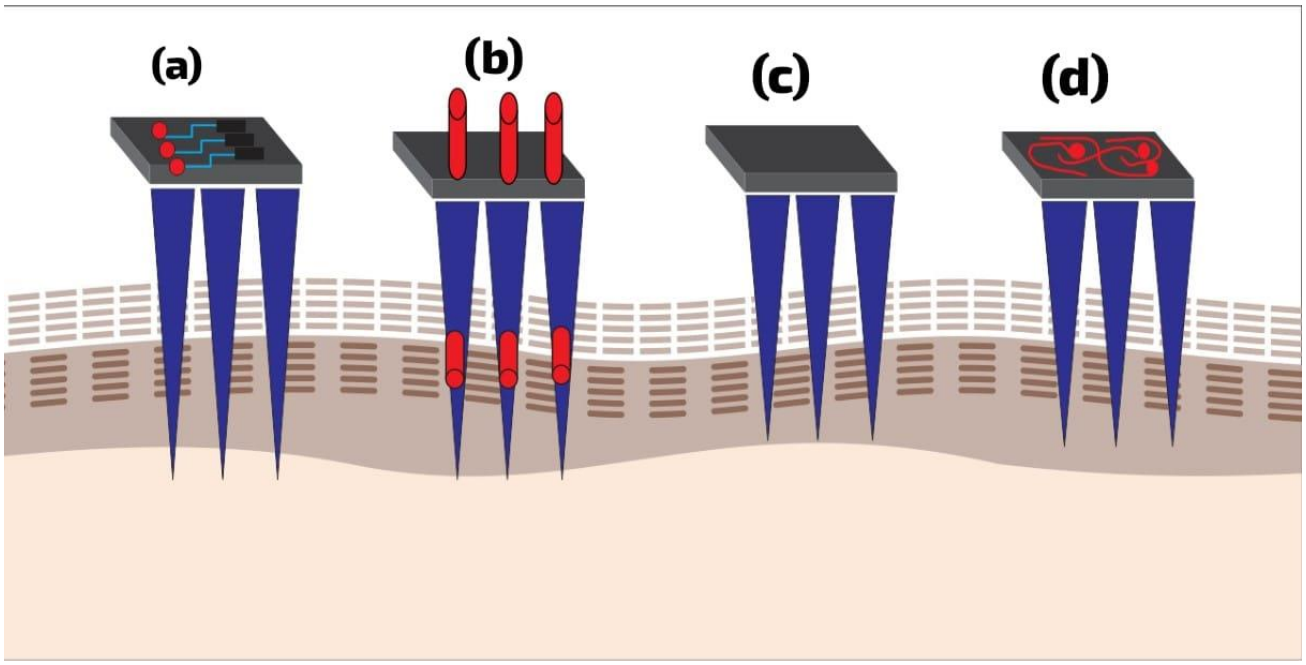


Figure 6: Microneedles (MNs) sensing modalities

(a) a sensor positioned on the MN base or support

(b) Electrode inserted into the hollow microneedles-acts electrochemically

(c) The surface of the MNs is functionalized to act as a sensor (d) MNs are metalized to act as bio-electrodes.[26]

Microneedle (MN) sensors consist of an analyte recognition element and a transducer, such as colorimetric MNs that use enzymes like glucose oxidase for analyte recognition. Immunosenor MNs use enzyme-linked immune sorbent assay, while hydrogel MNs immobilize nucleic acids. Wearable orthogonal MNs have been developed for monitoring levodopa levels in Parkinson's disease patients. Gold nanorod-coated MNs have been used for synergistic tumor therapy, and controlled-release MNs of 5-fluorouracil and indocyanine green are being developed for skin cancer treatment. Different analytes targeted for cancer detection using MNs include glucose, glutamate, lactate, hydrogen peroxide, nitric oxide, potassium levels, and T-cell detection. [27]

Table 1: Various sorts of analytes depended on to recognize disease utilizing microneedles.

Name of the Analyte	Principle Involved in Detection	Structure and Materials for Sensor	Test Subject	Ref
Glucose	• Colorimetry • Glucose assay • Electrochemistry	• Hydrogel solid MNs • Metal hollow MNs and paper sensor • Silicon hollow MNs and sensor	• Mouse • Rabbit • Human	28,29
Glutamate	Electrochemistry	Hollow or solid MNs of a polymer	-	30
Lactate	Electrochemistry	Hollow or solid MNs of polymer along with carbon paste or carbon nanotubes	-	30
Hydrogen peroxide	Electrochemistry	Solid MNs with platinum or gold electrodes	Mouse	30
Nitric oxide	Electrochemistry	Solid MNs of a polymer or metal with hemin or graphene that is functionalized.	Melanoma mouse Rat	31,32
T cell	Immune response	Solid MNs of polymer with antigens (nano-capsule)	Human skin	33
Potassium	Electrochemistry	Hollow MNs of polymer or metal with ion-specific electrode	Porcine skin	34,35

Breast Cancer Treatment Using MNs

Skin malignancy is the second most common disease that will eventually kill women after breast disease. Some of the treatments include chemotherapy that will prevent the recurrence of the cancer or careful resection to remove the local growths. Generally, chemotherapy involves the foundational organization of the counter dangerous medications that often result in other adverse effects like concealment of bone marrow, cardiovascular and extra neurotoxicity, mastectomy, chemical treatment, lumpectomy, radiation treatment, and natural treatment using macromolecules. [36] Finding a better line of therapy doctors shifted their attention towards immunotherapy and cancer vaccines.[37] Bhatnagar et al. published MNs of zein (prolamine protein from maize) for drug delivery of tamoxifen and gemcitabine, which are applied in the treatment of breast cancer. Zein MNs were made through the molding process by dissolvable casting, incorporating 3D printing of the expert form using a polymer, cyclobutyl nitrile styrene, and plasticizers specifically glycerol and Stake 400. [38] Tamoxifen and gemcitabine were characterized in zein MNs. Meanwhile, the counter bosom cancer drugs were also coated on zein MNs using rhodamine as a dye to study the properties of coatings. Delivery studies on loading efficiency showed that there was more tamoxifen loading onto zein MNs than gemcitabine. Considering the delivery dynamic studies, it revealed more penetration of gemcitabine counter tamoxifen. The review summarized that the maximum solubility of a drug in water may display improved permeation when administered using zein MNs. Bhatnagar et. Al. also conducted a dissolving MNs composed of polyvinyl pyrrolidone and polyvinyl alcohol for coding of doxorubicin and docetaxel to treat breast cancer. The MNs were fabricated Involving a micro-molding process as recently explained, drugs (doxorubicin and docetaxel) were loaded by encapsulation process employing polyvinyl pyrrolidone (PVPK360), and the substrate plate was prepared by use of both PVPK360 and polyvinyl alcohol. The pre-prepared MNs dissolved within less than 60 minutes after it was implanted in the skin. They used 4T1 breast cancer cells to assess the efficacy of MNs. The toxicity focus on animals revealed that the presentation of both drugs using MNs showed a higher survival rate than that of injections (intratumoral). Co-administration of these two drugs proved to have controlled the progression of the tumor than when administered separately. [39]

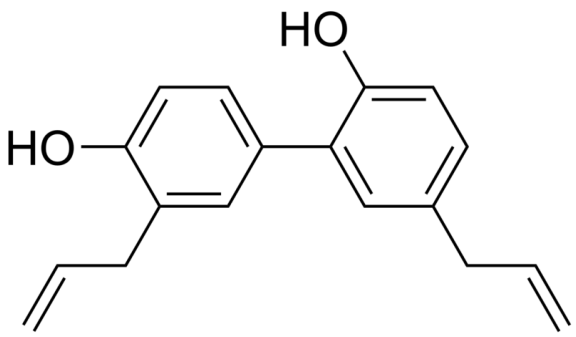


Figure 7: Honokiol (C18H18O2): A biphenolic natural compound isolated from the leaves and barks of Magnolia plant species [39]

Reports further indicate that Magnolia glandiflora contains other anticancer properties; breast prostate liver. MNs formed from maltose were utilized in delivering honokiol through various layers of skin and also via the mammary papilla. In addition to honokiol delivered by MNs, Gao, and co-authors concentrated on the delivery of this natural anticancer drug by Utilizing skin saturation enhancers. The assessment used synthetic enhancers such as propylene glycol, oleic acid, and isopropyl myristate. Oleic acid was observed to be an excellent permeation enhancer compared to the other agents. The two delivery systems (MNs and permeation enhancers) were observed to be promising and economical for the transdermal delivery of honokiol across the skin layers. [40] In addition, the anti-cancer activity of honokiol was observed with reduced release of cytokine interleukin-6 and Ki-67 protein staining. Chablani et al. applied metallic MNs (AdminPatch® 1200) for particulate 1.5 μm size breast cancer immunization prepared by freeze-drying method.[41] Mojeiko et al reported the application of MNs to increase the penetration of celecoxib microemulsion in the treatment of breast cancer. MN-based roller treatment in combination with microemulsion containing 60% water was seen to significantly increase celecoxib penetration through the layers of mammary tissue. [38] In addition, MNs can be used for drug delivery by the transcapillary course (breast) for the treatment of breast malignancy. [42] Chen et al. used MNs with a nano-silver/MBL layer that modulates the siphoning effect for the early diagnosis of breast disease. The approach utilizes the deposition of MNs at the correct region of the breast thus creating a way out for the interstitial space to collect the sample/cells. Due to the siphoning effect of the movie the cells are uptaken onto the layer which is exposed to colorimetric analysis for the detection of early stages of breast cancer in patients. [43] Zandi et al. reported that MNs of electrochemical tests doped with zinc-oxide nanostructures were used for the fabrication of microbubbles. Following the mixing of such MNs into the growth interstitial fluid, sonoporation was used for the formation of microbubbles by electrolysis for the transport of paclitaxel. [20]

MNs Used in Skin Carcinoma

Skin carcinoma is the most common type of malignancy and statistics show that one in every five individuals in the United States would be diagnosed with it during their lifetime. There are three types of skin cancer basal cell carcinoma, squamous cell carcinoma, and melanoma carcinoma. The former two are more common than the latter; a more dangerous one compared to the other two.[44] Skin disease is essentially caused due to prolonged exposure to UV radiation. Conventional treatments like chemotherapy, radiotherapy, careful resection, and immunotherapy are related to several limitations. In addition, anticancer drugs when given via the oral or parenteral route will be subjected to gastric degradation or first-pass effect in this way resulting in various side effects. MNs appear to be the safest options considering the above barriers.[45] North Carolina State College

authors Zhen Gu and others reported self-degradable and supported release MNs repair of PD1 antibodies (nivolumab, and pembrolizumab) either alone or in combination with anti-CTLA4 immunizer (ipilimumab). The developed MN repair includes a base end further, the tip coated with nanoparticles that characterize the immunotherapeutic expert (PD1 inhibitor or potential anti-CTLA4 immune response) with glucose oxidase as a pH modifying specialist.[45] The nanoparticles arranged were acidic degradable and arranged using dextran and sodium alginate as surfactants. In some encapsulations, Zhen Gu and co-authors used hyaluronic acid in the preparation of MN patches, which helps lubricate the strata of the skin as soon as the fix is implanted. Zynerba Drugs, a US company discovered MNs containing cannabidiol and its prodrugs that are likely to be used in pancreatic cancer. It proposes hydrogel, the reservoir type of fixation of MNs.[46] Eirion Therapeutics submitted two international patent applications on transdermal transport of huge sub-molecular weight particles that are used in the treatment of skin disorders. The synthesis promised a method for delivering an emulsion composition of botulinum toxin (molecular weight of 100,000 kDa) with an intracellularly active agent (hydrocortisone, lidocaine, Retin A, and others). The method of interest involved steps of skin modification through MNs, followed by the application of the definition. They have integrated the microneedle technology with emulsion technology (water-in-infinitely oil-in-water Nanoemulsions) to deliver botulinum poison, a huge sub-atomic compound. The emulsion definition too Included non-interfering and infiltration-improving specialists, for example, "cationic peptide" and a decidedly charged transporter having the arrangement "RKKRRQRRRG-(K)15-GRKKRRQRRR". The innovation too Uncovered the utilization of high atomic weight organically dynamic specialists like infliximab, golimumab, adalimumab, certolizumab pegol, siplizumab, and others either alone or in blend with one another. [47,48] Lu and associates accounted for dacarbazine stacked MNs for skin carcinoma. The MNs were prepared by miniature stereolithography with a polymer of poly (propylene Fumarate) and diethyl fumarate added for the control of polymer thickness. The pre-arranged MNs have a barrel-shaped base and a tapered tip with bright skin inclusion force. Dacarbazine was delivered in a controlled design for more than five weeks.[49] Hamdan and co-worker further explained the breaking of "5, 10, 15, 20 -tetrakis (2, 6-difluoro-3-N-methylsulfamoylphenyl bacteriochlorin", a pre-formed photosensitizer (near IR). The experiments showed that the MNs were vigorously tough mechanically to be driven into the layers of the skin, 5mm deep the skin for the treatment of nodular skin carcinoma. So, in the paper, the authors proposed polymeric (copolymer of methyl vinyl ether and maleic acid) MNs for the photodynamic treatment of deep skin ulcers.[50] Al-mayahy and others reported the use of MNs to facilitate the infiltration of imiquimod for basal cell carcinoma treatment.[51] In other research involving imiquimod, Sabri and others claimed to use oscillating MN pens 'Dermapen' and 'Dermastamp' to improve the penetration of imiquimod when used as a cream by 'jab and-fix' and 'fix and-jab' Methodologies. Discharge dynamic examinations affirmed that imiquimod entrance was in every way higher at the point when managed by the 'fix and-jab' strategy with the help of 'Dermapen'. The brilliant clarification for the same was due to the MNs causing the formation of the intra-dermal terminal of medication and isosteric corrosive (cream excipient) that lingers for around a day.[52] The MNs were organized utilizing CMC, wherein the medications are saved by miniature processing technique as medication freight layers, as appeared in Figure 8, (reorganized from specific reference). Jiangsu School of Data Innovation presented semiconductor-based microneedles that help not just for quality conveyance yet in addition for the conveyance of anticancerous drugs.[53]

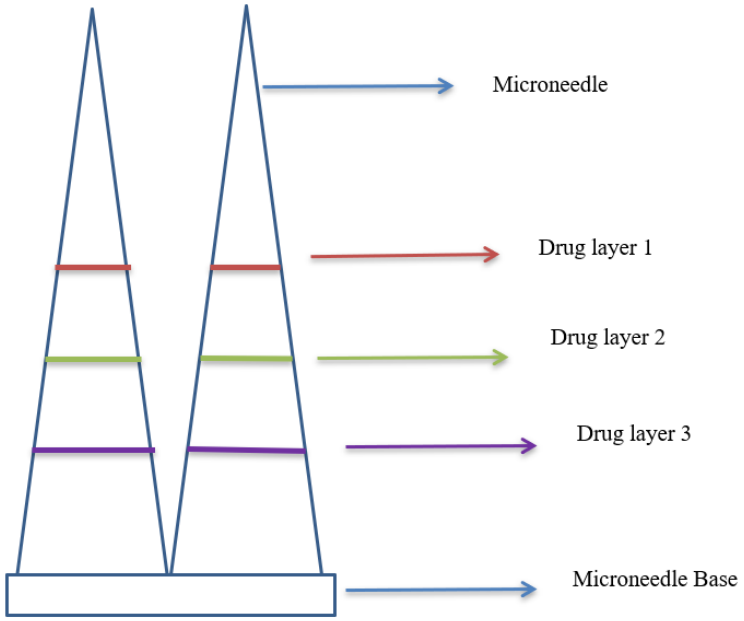


Figure 8: Cross-segment of the microneedle after drug freight stacking by miniature processing.[53]

MNs for Prostate Cancer Treatment

The second most common disease in men after cellular damage in the lungs is Prostate Malignant growth (PC). It is frequently discovered in the male population of the developed nations and the death rate is just behind lung and colorectal malignancy. Available treatment modalities for PC include but are not limited to aggressive prostatectomy (surgical intervention for early-stage PC), radiotherapy or image-guided radiotherapy, Androgen Distress Treatment (ADT) either alone or in mixed with radiotherapy and brachytherapy (radioactive material is situated inside the body).[54] The emasculation obstruction seen in ADT is dealt with utilizing different medications in particular abiraterone acetic acid derivation (CYP17-α-hydoxylase inhibitor), docetaxel, prednisone, cabazitaxel, and enzalutamide. Disease antibodies, like PC DNA immunizations, are different options that can be utilized to target cells that are communicating immunogenic cancer-related antigens (TAAs). In any case, Late clinical Phase I trial results regarding PROSTVAC raised concerns over the application of DNA antibodies alone. A PC DNA immunization feasibility can be improved by an appropriate drug delivery system such as MNs. MNs have the aesthetic beauty that the drug can be delivered locally to the tumor site across the layers of the skin to the Antigen Presenting Cells (APCs) in the epidermis and dermis regions.[55]

Chen et al. showed transdermal delivery of goserelin (LHRH simple) using soluble polymeric MNs of Chitosan and polyvinyl alcohol/polyvinyl pyrrolidone base as a support. LHRH for every microneedle was 73.3 ± 2.8 µg.[56] The pores that are created after the penetration of the skin would seal off after 7 days and the serum LHRH levels increased first and then decreased at the end of the seventh day. About the testosterone levels, they increased to peak by the fourteenth day and decreased to the level of maiming by the end of the 21st day. In addition, electrically utilitarian MNs were reported in human PC cells in vitro by electroporation technique. Choi and colleagues published MNs fabricated by micro molding technology to electroporate human PC cells for enhancing transfection by DNA immunizations.[57,58] Recently, Cole and others first demonstrated a highly effective two-layered microneedle-based stage for PC DNA immunization delivery. In its pilot, the RALA/pDNA nanoparticle-based dissolving polymeric microneedle framework was designed to vaccinate mice encoded with mPSCA (Prostate Stem Cell Antigen). The results of the pilot indicated the creation of encoded PSCA. In addition, inoculation with RALA/pPSCA-based MNs manifested anti-cancer activity.[59]

Future Aspects of MNs

Microneedling, a minimally invasive skin treatment, is primarily used in dermatology for conditions like acne scars, wrinkles, and hyperpigmentation. However, its potential in cancer therapy is emerging as a promising frontier. Microneedling could revolutionize the delivery of drugs, vaccines, and therapeutic agents directly into tumor tissues, overcoming the limitations of traditional cancer treatments. One of the primary advantages of microneedling is its ability to enhance the delivery of drugs directly into the skin or tumor tissue. This can be particularly beneficial in treating skin cancers like melanoma or other cancers that affect surface-level tissues. Microneedles can create microchannels in the skin, allowing for localized, controlled, and deeper penetration of chemotherapy agents, immunotherapy drugs, or gene therapy constructs. This targeted drug delivery reduces the need for systemic administration, thus minimizing side effects and improving therapeutic efficacy. Microneedling also offers potential when combined with other cancer treatments like photodynamic therapy (PDT), immunotherapy, or radiation therapy. In photodynamic therapy, for example, microneedling can be used to deliver photosensitizing agents directly into the tumor, enhancing the efficacy of light-based treatments. Similarly, microneedling could improve the effectiveness of cancer vaccines by facilitating the transdermal delivery of antigens, boosting the immune response against tumors. Another important future aspect of microneedling in cancer therapy is its potential to address the challenge of drug resistance. Traditional cancer treatments, particularly chemotherapy, often lead to drug resistance, wherein cancer cells mutate and no longer respond to the drugs. By using microneedles to deliver drugs directly to tumor cells, researchers can potentially bypass some of the mechanisms that lead to drug resistance. Microneedling can also enable the use of combination therapies that target multiple pathways, reducing the likelihood of resistance developing.

Conclusion

Microneedling, a cosmetic procedure involving tiny needles to create controlled micro-injuries, is being researched for its potential in cancer therapy. It has advantages such as enhanced drug delivery, immune response stimulation, and tissue regeneration. Microneedling can improve the penetration of anticancer agents, reducing side effects and increasing efficacy, especially in cutaneous malignancies like melanoma. It also stimulates the immune system, aiding in the recognition and attack of cancer cells, and can be combined with immunotherapies for better outcomes. Additionally, microneedling can enhance other cancer therapies like PDT or gene therapy and promote tissue regeneration to reduce damage from treatments like radiation or surgery. However, before microneedling can be widely used in cancer treatment, more clinical trials are needed to establish safety and efficacy in different cancers and patient groups. Standardized protocols are necessary to ensure consistent results. Questions regarding needle size, treatment frequency, and combination with other therapies need further investigation. Nevertheless, microneedling shows promise in enhancing drug delivery, stimulating immune responses, and aiding in tissue regeneration for cancer patients. It has the potential to improve treatment outcomes, minimize toxicity, and become a valuable addition to cancer care strategies in the future.

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