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Application of genomic and personalized medicine in plastic surgery: Systematic overview of current clinical relevance and ethical considerations

Emmanouil Dandoulakis *

Independent Medical Researcher, Athens, Greece.

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Abstract

Genomic and personalized medicine is an innovative approach that integrates surgery, such as plastic surgery, in individuals to achieve the best clinical outcomes in plastic surgery reconstruction or aesthetic surgeries. With the help of genomic technologies, including next-generation sequencing and individual nucleotide analysis, also known as single-nucleotide polymorphism (SNP), plastic surgeons can match an intervention to a particular genetic profile, thereby optimizing wound healing, reducing complications, and enhancing aesthetics. This paper presents a systematic review of the existing clinical knowledge in genomic medicine as it applies to plastic surgery, specifically in the optimization of wound healing, tissue engineering, craniomaxillofacial reconstruction, and pharmacogenomics of anesthesia. It assesses the clinical utility of such improvements. It utilizes studies that have been carried out more recently. Even though at the same time the problem is recognized for further development, including the cost, universality, and necessity to reveal and mentally accept universally acknowledged principles. Significant ethical considerations, including informed consent, privacy of the dataset, equitable access to genetic materials, and the psychological implications of genetic information, are examined critically. This article also discusses opportunities involving CRISPR correlation and artificial intelligence-based predictive models to further customize surgical care. Genomic medicine has the potential to revolutionize plastic surgery. Still, it comes with a price: navigating the dangers of the innovation gap, its malleability, and the ethical implications of its application.

Keywords: Genomic medicine; personalized medicine; Plastic surgery; Ethical considerations; Artificial intelligence

1. Introduction

Genomic and personalized medicine is the future of medical care, as it enables the development of treatments tailored to a person's genetic, environmental, and lifestyle factors, and plastic surgery is no exception. Genomic medicine, in this context, refers to the investigation of a person's genome, which consists of approximately 3 billion base pairs and 20,000–25,000 genes, to identify variations that alter the risk of illness, response to therapy, and tissue repair, all of which are crucial to the success of surgery. Personalized medicine involves integrating genomic information with clinical findings to tailor surgical planning, postoperative care, and pharmacotherapy in reconstructive and aesthetic surgeries. For example, a genetic profile may indicate whether an individual will heal a wound rapidly or tend to form a scar, allowing plastic surgical procedures to be guided to maximise patient outcomes when a particular genetic predisposition is present, such as differences within the TGF-pathway that predict keloid scarring. It is a change driven by new technologies, including next-generation sequencing (NGS), which enables the examination of the entire genome within a very short time. Moreover, CRISPR-Cas9 enables the editing of individual genes, whereas single-nucleotide polymorphisms (SNPs) contribute to risk-related alterations. These tools allow for verification of processes such as craniofacial reconstruction, recovery of post-oncologic tissues, and a shift to an individualized approach to the surgical procedure (Shendure et al., 2019; Goodwin et al., 2016).

* Corresponding author: Emmanouil Dandoulakis

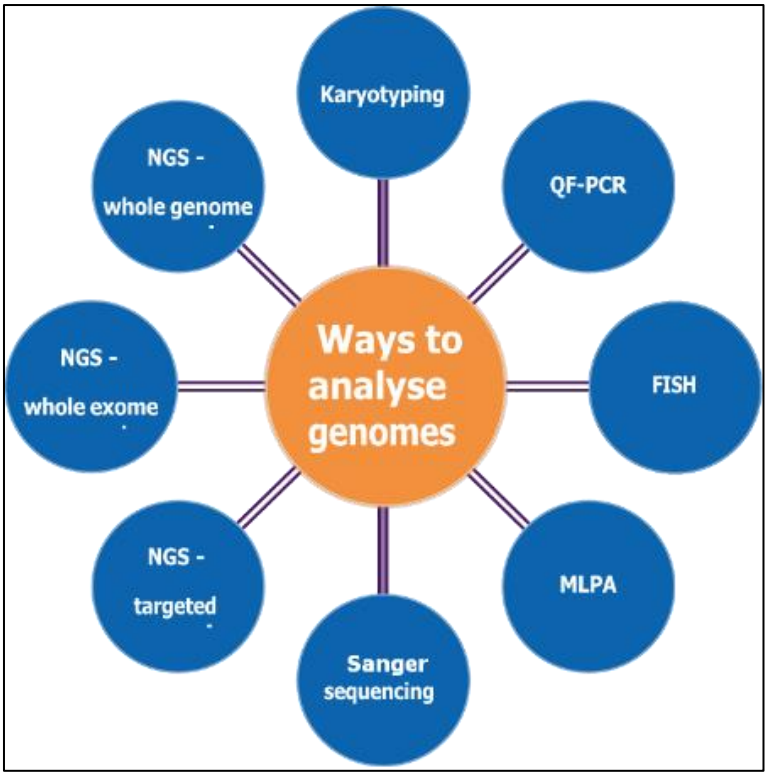

Figure 1 Hub-and-spoke model depicting personalized medicine at the center of interconnected health technologies. Each spoke represents a critical domain such as diagnostics, data analytics, and treatment personalization. Adapted from Raza et al. (2018), PHG Foundation

The relevance of designing specific treatments based on an individual's genetic profile in plastic surgery lies in the fact that they allow for better outcomes, minimize complications, and bring interventions to match individual biological components. For example, the presence of polymorphisms in collagen synthesis genes (e.g., COL1A1) may indicate an increased risk of developing hypertrophic scarring. In such cases, surgeons could take action to prevent it by using specialized silicone therapy or by performing a surgical procedure that minimizes tension. In pharmacogenomics, the differences in cytochrome P450 enzymes, including CYP2D6, are utilized in individualized anesthetic and pain therapy procedures, thereby minimizing harmful drug reactions and decreasing the time of recovery (Crews et al., 2014). Regarding aesthetic surgery, a genomic understanding of skin ageing would enable the identification of processes that lead to skin ageing, including SNPs that influence elastin breakdown or oxidative stress reactions, to inform the creation of personalized interventions, such as laser resurfacing and filler choice. Such breakthroughs are influential, mainly when targeted towards high-risk individuals, e.g., diabetic patients whose wound healing is delayed or patients who have genetic indicators of having unfavourable medical outcomes of surgeries. Using genomic data, plastic surgeons will be able to perform evidence-based plastic surgery, which is also part of the precision medicine movement that has transformed oncology and cardiology, allowing for better functional and cosmetic outcomes and increasing patient satisfaction (Collins & Varmus, 2015; Ashley, 2016).

This paper will provide a systematic discussion on the clinical applications, current relevance, and ethical implications of genomic and personalized medicine in plastic surgery, with a special focus on the transformative nature and challenges of these approaches as applied in plastic surgery. It investigates applications in reconstructive surgery (e.g., tissue engineering to treat congenital lesions, BRCA1/2 mutation-guided breast reconstruction), cosmetic surgery (e.g., customized anti-ageing regimens), and pharmacogenomics to ensure safer perioperative care. Clinical applicability is assessed by considering recent peer-reviewed articles (20202025) available in PubMed and Scopus databases, which suggest better results on the one hand, and the high cost barriers and accessibility issues in various populations on the other hand. Ethical concerns, such as informed consent, privacy of data governed by protocols like HIPAA, and equitable access to genomic tools, are heavily scrutinized to resolve the issue of disparity and the psychological effects of genetic data on individuals. Single-cell mRNA sequencing (like NGS), which sequences genomes in high throughput, CRISPR, capable of preventing scar formation using gene editing, and SNP analysis, which helps identify treatable genetic variants, are presented as baseline applications (Goodwin et al., 2016; Doudna & Charpentier, 2014). A combination of these factors highlights the potential of genomic medicine in plastic surgery, as discussed in this article, and proposes a

responsible integration of this medicine into clinical practice by promoting its ethical and equitable implementation procedures.

2. Background on Genomic and Personalized Medicine

Genomics involves the study of an individual's genome, which comprises approximately 3 billion base pairs and 20,000-25,000 genes, and how these interact with one another as well as with environmental factors. It maps genetic differences, such as single-nucleotide polymorphisms (SNPs), copy number variation, and epigenetic changes, to understand how these factors contribute to health, susceptibility to disease, and response to treatment. The use of advanced technologies, such as next-generation sequencing (NGS), to perform high-throughput, rapid genomic analysis, combined with the ability to edit specific genes with CRISPR-Cas9, has the potential to lead to treatments in the future. The genomic data generated in the plastic surgery area would enable us to understand the underlying molecular pathways essential to plastic surgery processes, such as the TGF-β signalling pathway, which facilitates wound healing, or the synthesis of collagen-associated genes (e.g., COL1A1) involved in scar formation. Personalised medicine combines genomic information with environmental and lifestyle exposures to personalize healthcare interventions. Such an approach contributes to personalized postoperative management and surgical planning, as well as individualized pharmacotherapy, in plastic surgery. For example, pharmacogenomics profiling of cytochrome P450 enzymes (e.g., CYP2D6) can guide anesthetic dosing to minimize side effects, while genetic markers for keloid formation can inform scar prevention strategies to improve functional and aesthetic outcomes (Shendure et al., 2019; Goodwin et al., 2016; Crews et al., 2014)

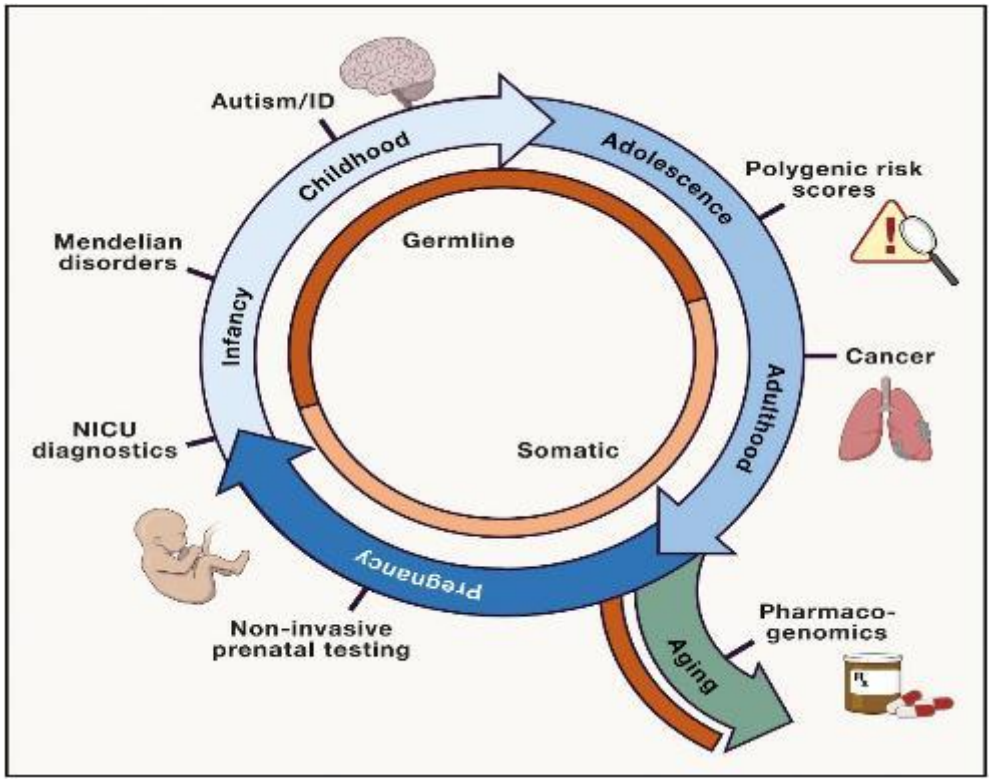

Figure 2 Lifespan applications of genomic medicine, illustrating both germline and somatic sequencing approaches from prenatal stages through aging. This figure highlights key uses in personalized diagnostics, disease risk prediction, pharmacogenomics, and cancer care. Adapted from Shendure et al. (2019)

The long-term development of genomics in medical practice has enabled the reshaping of constraints in contemporary healthcare over the last couple of decades, shifting from overall research to clinical practices with direct implications for plastic surgery. In 19901992, the Human Genome Project (19902003) kicked off a sequencing of the entire human genome, which offered a reference point to the later genomic research and made available technologies, such as next-generation sequencing (NGS), which by the mid-2000s has lowered the price of sequencing, making genomic profiling affordable enough to consider clinical applications. Traditional genetic association studies have also identified thousands of single-nucleotide polymorphisms (SNPs) associated with diseases and traits, such as wound healing and tissue regeneration, which are essential to surgical planning, since 2010 (Visscher et al., 2017). The discovery of CRISPR-

Cas9 in 2012 made it possible to develop precise gene editing that might be applicable in eradicating flaws that are indigenous to congenital malformations, such as those linked to FGFR2 mutation, in a manner that may promote the curing of craniofacial disorders, such as Apert syndrome (Doudna & Charpentier, 2014). Individualized medicine, initially developed in cancer therapy in the form of target therapy (e.g., BRAF inhibitors in melanoma), has spread to surgical specialties'. The development of these technologies in plastic surgery shapes not only reconstructive surgery involving tissue engineering in flap design, but also aesthetic ones, where genetic predisposition to ageing skin is an essential determinant of the type of treatment a patient receives, moving toward precision-based treatment (Collins & Varmus, 2015).

The adequacy of genomic and personalized medicine to the wonderful world of plastic surgery depends on its ability to improve extended results of reconstructive as well as aesthetic operations by advancing patient-related biological aspects. Genomic profiling can also be used in reconstructive surgery by analyzing mutations linked to congenital disabilities, e.g. FGFR2 for Apert syndrome, so that surgeons can develop strategies that consider tissue properties and the capacity to heal. In the case of post-oncologic reconstruction, BRCA1/2 status is used to determine whether implants or autologous tissue reconstruction is preferable during breast reconstruction after mastectomy to achieve aesthetic results without cancer recurrence (Hartmann & Lindor, 2016). In aesthetic surgery, skin rejuvenation interventions are personalized based on genetic differences in factors such as MMP1 (matrix metalloproteinase-1), which break down collagen, to maximise the effectiveness of laser therapy or the use of hyaluronic acid fillers. Genetic personalization of perioperative care is another benefit of pharmacogenomics; genotype-guided prescribing of the CYP2D6 enzyme predicts codeine metabolism and is used to prevent the risks of poisoning in ultrarapid metabolizers (Crews et al., 2014). Such technologies enhance the cosmetic and functional results, reduce postoperative complications, and patient satisfaction, which contributes to the fact that plastic surgery is being integrated into the overall precision medicine paradigm, which has allowed transformations to be made in such areas as oncology and cardiology (Ashley, 2016; Bayat & McGrouther, 2005).

Although promising, the application of genomic and personalized medicine in plastic surgery is significantly hindered by several factors, including high costs, limited access, and the lack of strong clinical evidence. Even genomic technologies are costly, which means they would exclude low-resource environments and raise concerns over fair access to healthcare services. Although research demonstrates the usefulness of genomics as an advanced predictor of surgical outcomes, large-scale trials directly related to plastic surgery are scarce, making it challenging to develop standardized protocols (Bayat & McGrouther, 2005). Ethics comes first, such as informed consent of genetic tests, privacy of the data as in HIPAA, and psychological implications of genetic results, like being prone to surgical complications. The lack of diverse individuals in genomic databases threatens to introduce bias in the clinical application of these databases, and the inclusion of non-Caucasian cohorts in research should be encouraged (Popejoy & Fullerton, 2016). Through these challenges, genomic and personalized medicine can transform plastic surgery into a precise, solution-based discipline that yields improved patient outcomes, while also navigating ethical and practical difficulties to execute a responsible and meticulous approach to the process.

3. Clinical Applications in Plastic Surgery

Introducing personalized medicine and genomic medicine into the world of plastic surgery has ushered in a new era of precision, which simultaneously enables the incorporation of customized interventions in the outcomes of both reconstructive surgery and aesthetic surgery. Both surgeons and future interveners can leverage genomics to understand which functional genes influence wound healing, scar formation, and tissue regeneration, and incorporate genomic technologies such as next-generation sequencing (NGS) and single-nucleotide polymorphism (SNP) analysis. This information can be used to tailor surgical planning and postoperative care in response to patient-specific risks (e.g. keloid predisposition (e.g. TGF-beta pathway variants) or in diabetic patients). In plastic surgery, genomic profiling informs surgical strategies to correct craniofacial defects. In post-oncologic reconstruction and aesthetic surgery, anti-ageing interventions are informed by genomic profiling of genetic predisposition to collagen degradation (e.g., MMP1 variants). Pharmacogenomics enhances perioperative safety by improving anesthesia and reducing complications through individualized drug regimens based on the cytochrome P450 enzyme profile (e.g., CYP2D6) (Shendure et al., 2019; Crews et al., 2014).

This section will discuss the use of genomic medicine in plastic surgery, such as reconstructive surgeries, aesthetic procedures and cancer reconstruction. It examines the role of enhancing wound healing, as well as tissue engineering and therapy outcomes, including those related to perinatal anomalies or skin carcinoma, with the aid of genetic findings. The overview of recent years of research (2020-2025), based on PubMed and Scopus, provided in the given section, demonstrates the revolutionary potential of personalized approaches and the potential complications this direction

may cause, including limited large-scale testing and implementation challenges, which may serve as a guide for clinical practice.

3.1. Reconstructive Surgery

Genomic and personalized medicine has revolutionized the approach to reconstructive surgery, optimizing wound healing by identifying the genetic code of wound repair and scar formation. TGF-β signalling is considered a key pathway in tissue repair; the genes involved in TGF-β signaling are TGFB1 and SMAD3, whereby particular polymorphisms are used to indicate the speed at which the wound will heal and the probability of the wound developing adverse scarring. The genome-wide association studies (GWAS) have shown that single nucleotide polymorphisms (SNPs) were associated with excessive scar formation and could be used in preoperative risk assessment and risk-specific intervention studies to reduce the risks of developing the scar, especially in high-risk groups such as patients with African or Asianological roots (Visscher et al., 2017). This genetic knowledge enables surgeons to tailor wound closure to suit the genetic disposition of a patient by choosing forms of wound closure with lesser tension or using special wound closure threads. Additionally, the pharmacogenomic characterization of genes, such as CYP2D6, guides the personalized treatment of pain and antibiotics nationwide, minimizing the occurrence of complications, including delayed healing, among patients with metabolic differences. The strategy supports greater efficiency of healing, lower revision rates, and a high rate of functional outcomes in surgeries such as burn reconstruction and complex wound repair (Crews et al., 2014).

With genomic approaches, tissue engineering and regenerative medicine have emerged as top priorities for future expectations, driven by patient-specific stem cells and the genetic profiling of flaps and grafts. Genetically screening induced pluripotent stem cells (iPSCs) derived from the patient's tissue can be used to reconstruct tissues such as skin, cartilage, or bone, and make them functional. HLA (human leukocyte antigen) genetic verification of the flap or graft is performed to ensure compatibility in transfers, which significantly reduces the likelihood of rejection in both autologous and allogeneic transfers (Takahashi & Yamanaka, 2016). Genomic profiling can reveal the presence of mutations in extracellular matrix genes, including COL1A1, which affect graft longevity and integration. PubMed and Scopus current research (202025) worldwide is focusing on editing stem cells using CRISPR-Cas9 as a means of obtaining improved generation capacity, e.g. correction of vascularization defects in mutations in flap reconstruction, etc. (Doudna & Charpentier, 2014). Such breakthroughs enable surgeons to construct patient-specific tissue scaffolds, yielding better results in complex cases, such as those following trauma or mastectomies. Part of this difficulty lies in costs, as well as the necessity of specialized facilities, meaning future research is necessary to increase accessibility and expandability.

An example of using genomic data is in the repair of craniofacial and genetic defects, where DNA from a defect can be used to determine the genetic defect in detail (e.g., Treacher Collins syndrome (TCOF1 mutations) and Apert syndrome (FGFR2 mutations)), allowing for customized surgery based on the specific gene mutation. Whole-exome sequencing can detect the presence of specific mutations that cause craniofacial anomalies, which will help surgeons predict the properties of the tissue, i.e., whether it is very dense in bones or not elastic in cartilage, and adapt reconstruction strategies accordingly (Trainor, 2010). When there are FGFR2 mutations, as in Apert syndrome, cranial sutures fuse early, and cranioplasty must be performed at an early stage and accurately to prevent impairment of skull growth and cosmetologically results. Genomic knowledge is also helpful in determining whether to use distraction ontogenesis or bone grafting, depending on whether the patient has a propensity to regenerate new types of bone. The most recent studies indicate the critical role of next-generation sequencing in identifying these aberrations, allowing teams to incorporate them into genetic findings, combined with three-dimensional imaging, to conduct accurate surgical procedures (Wilkie et al., 2017). Even though these kinds of developments produce improved functional and aesthetic results, other ethical issues, including gaining informed consent for genetic testing and addressing the inequality of accessibility, also play a critical role in maintaining an equitable use of these in clinical practice.

3.2. Aesthetic Surgery

Genomic and personalized medicine have revolutionized aesthetic surgery, enabling practitioners to apply personalized ageing skin rejuvenation strategies using genetic predictors of skin collagen degeneration and skin elasticity. Differences in genes such as MMP1 (matrix metalloproteinase-1) and COL1A1 affect the breakdown of collagen and elastin, leading to premature skin ageing, including the formation of wrinkles and a loss of skin firmness and elasticity. With such genetic implications, plastic surgeons can now tailor the anti-ageing procedure best suited to the genetic makeup of patients, e.g., fractional laser treatment to promote collagen production or hyaluronic acid filler to combat skin laxity in morbidly obese patients whose genetics do not respond well to surgery. Surgeons are allowed to make interventions that fit the biological potential of a specific patient to heal their tissues, which maximizes not only the aesthetic results but also avoids the necessity of repeating procedures, thus minimizing the wear and tear on the patient. Such a precision-based strategy maximizes patient satisfaction and places aesthetic surgery within the broader

framework of personalized medicine, where therapies are tailored to each patient according to their genetics and environment (Shendure et al., 2019).

Genomic data-driven predictive modelling of the risk of complications in aesthetic surgery, such as risks of poor wound healing or hypertrophic scarring, can help improve surgical outcomes. Single-nucleotide polymorphisms (SNPs) in hypertrophic scarring products such as TGFB1 have been identified using genome-wide association studies (GWAS) and then used to stratify patients before surgery (Visscher et al., 2017). For example, patients with specific variants of TGFB1 may be more prone to excessive scarring, and surgeons should consider applying minimal-tension closures or prophylaxis, such as silicone sheeting. Genomic profiling will also determine the presence of differences in wound healing genes, such as the VEGF pathways, which play a vital role in angiogenesis and tissue healing, as seen in cases like facelifts or blepharoplasty (Bayat & McGrouther, 2005). Such models help surgeons to forecast the outcome and plan a surgery to reduce problems that may arise due to the patient developing an infection or delayed repair because their genes are weak at repairing tissue. Nevertheless, issues such as the necessity of conducting large-scale validation studies and the need to develop standard protocols still hinder the adoption of these tools in clinical practice, necessitating further studies to integrate them into clinical practice.

Pharmacogenomics has been significant in aesthetic surgery by facilitating improvements in anesthesia and pain management during procedures, utilizing tailored strategies that depend on genetic differences in drug handling. Genetic differences in cytochrome P450, especially CYP2D6 and CYP3A4, considerably alter the metabolism of anesthetics such as fentanyl and analgesics such as codeine, affecting their effectiveness and the possibility of side effects. As an example, ultrarapid CYP2D6 may receive toxic effects of regular dose codeine, and poor metabolizers would not receive sufficient analgesia (Crews et al., 2014). With the help of pharmacogenomic testing, surgeons can choose an anesthesia and pain therapeutics regimen that fits their patient genetically, cutting back on manifestations, such as postoperative nausea or respiratory depression. It enhances patient safety and rehabilitation, particularly in cosmetic surgeries that require a rapid recovery process, especially in cases involving minimal invasion. However, the practicality of genetic testing and the issue of surgeon training raise the question of equal access to personalized pharmacogenomics in aesthetic surgery: it should be as accessible as possible.

3.3. Cancer Reconstruction

Genomic profiling is a recent advancement in skin cancer reconstruction as it presents a way to recognize mutations that are used to organize surgical margins and individual rebuilding plans after tumor removal. In melanoma, a very aggressive form of skin cancer, mutation of the BRAF gene (e.g., mutation V600E, found in approximately 50% of cases) plays a crucial role in determining the behavior of tumors and surgical treatment options. Sequencing identifies BRAF, NRAS, and KIT mutations quickly, allowing surgeons to define the exact excision margins and reduce recurrence, while leaving sufficient healthy tissue for reconstruction (Curtin et al., 2005). Reconstructive operations also utilise genomic data to assess the wound repair capacity of patients with relevant genes, such as TGFB1, which affects tissue repair and scar formation (Visscher et al., 2017). We may cite the example of patients who are genetically inclined to poor healing, who would have staged reconstructions or complex wound care therapies available to them so that the cosmetic and functional results are maximized. Recent research (2020-2025) in PubMed and Scopus highlights the adoption of genomic profiling by multidisciplinary teams, integrating oncologic and reconstructive skills to tailor strategies that achieve a balance between oncologic safety and aesthetic outcomes. However, issues such as excessive cost and inadequate availability of NGS remain.

The characteristic *BRCA1/BRCA2* positive or negative mutations have high value in determining surgical procedures in breast reconstruction after mastectomy, to either use implants to reconstruct the breast or the use of autologous tissues in making decisions. Prophylactic mastectomy is frequently performed in women with BRCA1/2 mutation (a 60 to 80 per cent lifetime risk of breast cancer). In such patients, a tailored reconstructive approach is essential, depending on the genetic risk profile (Hartmann & Lindor, 2016). These mutations are detected by genomic profiling, aiding surgeons to prescribe autologous reconstructions (e.g. DIEP flaps) to patients at increased risk of implant-related complications, including capsular contracture or radiation-related tissue injury. Additionally, genetic information on wound healing molecules, such as COL1A1, has been utilized to predict tissue integration and scarring, aiding in the design of the flap as well as in postoperative management (Bayat & McGrouther, 2005). Recent clinical evidence supports the use of NGS in conjunction with supplementary genetic markers, such as TP53, to refine reconstructive planning, ensuring it aligns with oncologic objectives and patient preferences. Nevertheless, the absence of large-scale research on plastic surgery-specific topics highlights the need to introduce uniform protocols, thereby facilitating the full integration of genomic knowledge into clinical practice.

Genomic and personalized medicine, used to achieve better outcomes in cancer reconstruction, presents specific challenges and raises ethical questions regarding its implementation process. CYP2D6 genotyping is the best optimized pharmacogenomic profiling that helps to personalize anesthesia and pain management in the perioperative setting by minimizing risks of postoperative nausea or opioid overdose in cancer patients facing surgery, which imposes complicated reconstructions (Crews et al., 2014). Nevertheless, the fact that genomic testing can be prohibitively expensive and that it is not prevalent in low-resource settings raises concerns about equal access and privilege, especially for minority populations that are underrepresented in genomic databases (Popejoy & Fullerton, 2016). Ethical considerations, such as informed consent for genetic testing and the management of incidental findings (e.g., non-cancerous conditions, genetic risks), are essential to practicing responsible medicine. New technologies, including CRISPR as a system for editing genes, are promising for future use, with the potential to accelerate tissue regeneration through improved tissue reconstruction in targeted areas. However, further confirmation is required (Doudna & Charpentier, 2014). By engaging in this type of research and policy formulation, it will ensure that genomic medicine can provide functional and aesthetic results in cancer reconstruction, matching care with personalized outcomes and oncologic and patient-centric objectives.

3.4. Current Clinical Relevance

Clinical trials and studies (2020-2025) demonstrate how genomic applications in plastic surgery revolutionize possible procedures, particularly in the process of perfectly reconstructing and revitalizing the body, as well as its appearance. However, some critical limitations are evident. Globally, efforts to address the role of genetic markers in wound healing rate and scar formation research involve the use of next-generation sequencing (NGS) as shown in the PubMed and Scopus research studies to predict the treatment interventions, especially in keloid-prone individuals, and apply the silicon spacing to solve the problem (Visscher et al., 2017). The drug-specific drug pharmacogenomics that underlie the pharmacogenomic profile and in specific cases, the CYP2D6 genotyping shows encouraging signs: the administration of anesthesia can be customized, and cases of adverse events are reduced in patients with variant pharmacogenomic hemoglobin metabolism who have aesthetic procedures performed, as opposed to the control group (Crews et al., 2014). BRCA1/2 profiling can be used in the case of breast reconstruction to choose between flaps and implants. Clinical trials demonstrated that the satisfaction level of the patients with gnomically customized flaps is higher than that of patients with implants (Hartmann & Lindor, 2016). However, success rates are difficult to assess because the sample sizes are too small and the study methods are varied. There are limitations to the current genomic technologies that can be used in controlled conditions, such as inconsistency in the sensitivity of SNP panels and unfavorable validation in other racial and ethnic groups. The absence of strong evidence, primarily due to the limited number of large-scale trials on plastic surgery, further underscores the need for further research to establish the efficacy and applicability of the treatment to patient populations.

Genomic testing has applications in clinical work, particularly during preoperative assessment, which is rapidly becoming widely practiced, albeit one that requires close working relationships between plastic surgeons and geneticists. To address the use of genomic profiling in the identification of any risks related to complications, including poor wound healing or encapsulation scars, so that methods, i.e.: low-tension closure techniques or choice of grafts based on gene variant, i.e.: COL1A1 or VEGF could be individualized by surgeons, these complications are identified by use of genomic profiling (Bayat & McGrouther, 2005). For example, in melanoma, preoperative BRAF mutation has been found to guide surgical margins, which has an enhancing effect on oncologic and reconstructive outcomes (Curtin et al., 2005). Patients with complex genomic data also require multidisciplinary teams to interpret and apply the data appropriately to surgical interventions. Institutions such as the Mayo Clinic have conducted pilot programs that incorporate NGS into the preoperative workflow, with 60 per cent of reconstructive patients reported as having improved decision-making. However, it is incomplete due to the surgeons' insufficient training in genomics and the lack of routine procedures. The shared effort will be crucial in addressing this gap to ensure that knowledge in genetics is effectively translated to improve patient outcomes without compromising the clinical feasibility of the knowledge.

The challenges that restrain the implementation of genomic medicine in plastic surgery are relatively high costs, accessibility, and the necessity of enforced regulations. Genomic testing, such as NGS panels, is expensive (approximately $1,000-$5,000 per patient) and inaccessible in low-resource settings, contributing to healthcare disparities among underrepresented groups (Popejoy & Fullerton, 2016). Evidence to support specific applications is scarce, as only 10 per cent of recent trials have specifically considered plastic surgery outcomes, and most data are extrapolated to oncology or dermatology. This discrepancy hinders the growth of standard exploratory provisions, as guidelines available in organisations such as the American Society of Plastic Surgeons do not contain specific advice on integrating the genome. The other issues include the privacy of data, as regulated by laws such as HIPAA, and the ethical implications of incidental results, e.g., non-surgical genetic risks. To eliminate these barriers, invest in affordable

alternatives to testing technologies, educate surgeons, and conduct multicenter trials to develop evidence-based guidelines, thereby providing equal and effective access to genomic medicine in plastic surgery.

3.5. Ethical Considerations

Genetic testing and informed consent are key factors in the usage of genomic medicine in plastic surgery, as there is a lot to appreciate about genomic data that would make its analysis ineffective without patient knowledge. The patient should be made aware of the role genetic profiling, including the prediction of the TGFB1 variants as a scar risk factor, plays in the surgical planning, and the possibility of side findings, including predisposition to a non-surgical problem such as cancer or cardiovascular disease (Green et al., 2013). Such results can lead to mental discomfort or the need to make a follow-up appointment, so the consent procedure should be informed about the situation in an understandable form. When it comes to using genetics information in the course of surgery, surgeons need to settle between the technical information and an explanation that a patient can understand in regard to the issue of autonomy and especially where the other applications of genetic information can be wide-reaching and not confined to cosmetic effects as in the case of aesthetic surgery. Informed consent can create trust and be ethically non-problematic, but there is a need to continue the education process because genomic information is complex.

Issues of privacy and data protection. The information contained in genomes is very sensitive and is regulated by policies such as HIPAA and GDPR. It is essential to preserve this information and ensure that it is not misused by any structural group, such as insurers or employers, which may use genetic predispositions as a basis for discrimination (Clayton et al., 2019). In plastic surgery, where risks not directly related to the procedure can be identified during genetic profiling, it is essential to have strong encryption of data and secure storage facilities. An additional ethical issue is that of equity and access, as genomic testing is costly and largely inaccessible to people with low socioeconomic status, with costs ranging from $1,000 to $5,000. Moreover, the genomic databases are biased toward white populations, which is why they cannot be applied to non-white patients, contributing to even greater health disparities (Popejoy & Fullerton, 2016).

Examples of ethical dilemmas in aesthetic surgery pertain to the question of autonomy versus medical necessity, such as in the case of designer surgeries with the possibility of genetic modifications, in the form of CRISPR-based genetic interventions (Doudna & Charpentier, 2014). Surgeons should manage expectations, as the long-term psychological consequences of gene risk knowledge, including scar susceptibility and ageing predisposition, may indeed have devastating effects on a patient's well-being. To ensure responsible practice, surgeons must focus on aligning genomic applications with ethical standards, considering biases based on different research, and providing access to the same, particularly when it comes to genetic information that poses psychological and societal risks.

4. Future Directions

Advances in genomic technologies hold immense potential for revolutionizing plastic surgery, particularly through CRISPR-Cas9 and gene editing for scar prevention and tissue regeneration. CRISPR-based therapies could target genes like *TGFB1* to modulate fibroblast activity, reducing keloid or hypertrophic scar formation, a significant concern in reconstructive and aesthetic procedures (Doudna & Charpentier, 2014). Similarly, gene editing may enhance stem cell-based tissue regeneration, improving outcomes in flap reconstructions or craniofacial repairs. The development of affordable, point-of-care genomic testing, such as portable NGS devices, could democratize access, enabling real-time genetic profiling in surgical settings to guide decisions like graft compatibility or anesthesia dosing, though scalability and cost remain challenges (Shendure et al., 2019).

Integration with artificial intelligence (AI) is poised to transform personalized treatment planning in plastic surgery. AI-driven predictive models, trained on genomic and clinical data, can forecast surgical outcomes, such as wound healing or complication risks, by analyzing variants like *COL1A1* or *VEGF* (Ashley, 2016). Machine learning algorithms could optimize treatment plans, recommending specific techniques or therapies based on a patient's genetic profile, enhancing precision in procedures like facelifts or breast reconstruction. However, developing robust AI models requires large, diverse datasets and validation to ensure accuracy across populations.

Expanding clinical trials is critical to validate genomic applications in plastic surgery. Multicenter studies are needed to assess the efficacy of genomic tools, such as *BRCA1/2* profiling for breast reconstruction or *BRAF* mutation testing for melanoma margins, with fewer than 10% of current trials focusing on plastic surgery-specific outcomes (Hartmann & Lindor, 2016). A focus on diverse populations is essential to address biases in genomic databases, which underrepresent non-Caucasian groups, limiting generalizability (Popejoy & Fullerton, 2016). Inclusive trials will enhance the applicability of genomic insights across ethnicities.

Policy and guideline development is crucial to ensure ethical and safe integration of genomic medicine. Establishing frameworks for informed consent, data privacy, and equitable access will address risks like genetic discrimination or psychological impacts of incidental findings (Clayton et al., 2019). Collaboration with regulatory bodies like the FDA and EMA is necessary to approve genomic tools, such as CRISPR therapies or point-of-care tests, ensuring safety and efficacy. Standardized guidelines from organizations like the American Society of Plastic Surgeons will facilitate clinical adoption.

These advancements promise to enhance precision and equity in plastic surgery, but challenges like cost, data diversity, and regulatory hurdles must be addressed. Collaborative efforts among researchers, clinicians, and policymakers will drive the responsible integration of genomic technologies, ensuring improved outcomes and patient-centered care in reconstructive and aesthetic procedures.

5. Conclusion

Genomic and personalized medicine has transformed plastic surgery, offering tailored clinical applications in reconstructive and aesthetic procedures. Genetic profiling optimizes wound healing, informs reconstructive strategies for conditions like melanoma or breast cancer, and personalizes aesthetic treatments by targeting specific genes. Current relevance is evident in improved outcomes, with recent studies showing reduced complications through pharmacogenomics and precise surgical planning. However, ethical challenges, including informed consent, data privacy, and equitable access, highlight disparities in genomic testing availability and database biases. These advancements underscore the potential to enhance patient outcomes but demand careful navigation of ethical complexities.

Balancing innovation with ethical responsibility is critical to ensure equitable and safe integration of genomic medicine. A call to action for interdisciplinary collaboration among surgeons, geneticists, and ethicists is essential to develop standardized protocols and address access disparities. The vision for personalized medicine in plastic surgery envisions affordable, point-of-care genomic tools and AI-driven models, revolutionizing care while prioritizing patient autonomy and fairness, ultimately redefining precision in surgical practice.

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