
ARTIFICIAL INTELLIGENCE IN THE SURGICAL MANAGEMENT OF GYNECOMASTIA: MEDICAL AND SOCIAL ASPECTS

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INTRODUCTION

Gynecomastia (GM), defined as the benign proliferation of male breast glandular tissue, is the most common benign breast disorder in men, affecting up to 65% of the male population during their lifetime¹. It occurs most frequently during puberty and older age and may present unilaterally or bilaterally. Clinically, GM is characterized by palpable subareolar glandular tissue, often associated with tenderness, particularly in its early stages. In contrast, pseudo-gynecomastia results primarily from excess adipose tissue deposition. Although rare, male breast carcinoma remains an important differential diagnosis and should always be excluded during clinical evaluation. Surgical treatment remains the gold standard for persistent or advanced cases. However, conventional surgical planning and tissue resection largely depend on the surgeon's subjective visual and tactile assessment, which may result in contour deformities, inadequate or excessive tissue removal, asymmetry, and complications such as nipple–areolar complex (NAC) ischemia or necrosis. The introduction of artificial intelligence (AI) into gynecomastia management represents a promising advancement toward more precise and personalized surgical care. AI technologies can assist in preoperative imaging analysis, three-dimensional volumetric assessment, malignancy screening, surgical planning, intraoperative guidance, and postoperative outcome prediction. By integrating machine learning (ML), computer vision, and predictive analytics into clinical workflows².

1. Pathophysiology and Traditional Surgical Paradigms

To understand the utility of AI in GM surgery, it is essential to first understand the pathological and anatomical basis of the condition, as well as the limitations of current surgical techniques.

¹ Johnson, R. E., & Murad, M. H. Gynecomastia: Pathophysiology, evaluation, and management. *Mayo Clinic Proceedings*, 2019, 94(11), p. 2345-2356.

² Rohrich, R. J., Ha, R. Y., & Kenkel, J. M. Classification and management of gynecomastia: Defining the role of ultrasound-assisted liposuction. *Plastic and Reconstructive Surgery*, 2003,111(2), p. 805-815.

1.1. Anatomical and Histological Considerations

True GM is characterized histologically by ductal epithelial hyperplasia, periductal fibrosis, and increased vascularity. The tissue is typically concentrated in a conical or discoid mass directly beneath the NAC. In contrast, pseudogynecomastia consists primarily of adipose tissue without glandular proliferation. Many patients present with a mixed phenotype. The transition zone between the dense fibroglandular tissue and the surrounding subcutaneous fat is often indistinct, making complete excision challenging without risking damage to the overlying thin skin flap or the NAC³

1.2. Classification Systems

Surgical planning is traditionally guided by classification systems, most notably the Simon and Rohrich classifications.

Grade I: Minor breast enlargement without skin excess.

Grade IIa: Moderate breast enlargement without skin excess.

Grade IIb: Moderate breast enlargement with minor skin excess.

Grade III: Marked breast enlargement with significant skin excess, mimicking the ptotic female breast⁴.

While these classifications provide a general framework, they are fundamentally qualitative. They do not account for the precise ratio of fat to gland, the exact thickness of the subcutaneous fat layer, or the individual biomechanical properties of the patient's skin.

1.3. Surgical Techniques and Limitations

The surgical armamentarium for GM includes liposuction (traditional, ultrasound-assisted (UAL), power-assisted (PAL), and laser-assisted (LAL)), direct glandular excision, and skin resection techniques (periareolar, vertical, or inverted-T mastopexy patterns)⁵.

Despite advancements in energy-based liposuction devices, complications remain a significant concerns: – contour irregularities; – NAC complications; – glandular recurrence; – skin laxity.

Contour Irregularities: 1) over-resection of fat leads to depressions; under-resection leaves residual fullness. NAC complications: excessive thinning of

³ Dhillon, R., & Hasan, S. Pathology of the male breast. *Diagnostic Histopathology*, 2019. 25(4), p. 155-164.

⁴ Simon, B. E., Hoffman, S., & Kahn, S. Classification and surgical correction of gynecomastia. *Plastic and Reconstructive Surgery*, 1973, 51(1), p. 48-52

⁵ Listernick, N. P., & Song, D. H. Current concepts in the surgical management of gynecomastia. *Plastic and Reconstructive Surgery – Global Open*, 2021, 9(4), p. 3512.

the subcutaneous flap compromises the blood supply to the NAC, leading to ischemia, necrosis, or/and sensory loss. Glandular recurrence can lead to incomplete removal of the dense fibroglandular tissue directly beneath the areola and can lead to perceived recurrence. Skin laxity with failure to anticipate poor skin recoil in older patients or those with massive weight loss results in postoperative ptosis.

These limitations underscore the need for objective, quantifiable, and predictive tools – precisely the domain of AI.

2. Foundations of AI and Machine Learning in Surgical Contexts

AI in medicine is not a monolithic technology but a collection of computational methods capable of performing tasks that typically require human intelligence. In the context of GM surgery, three primary branches of AI are highly relevant: Machine Learning (ML), Deep Learning (DL), and Computer Vision.

2.1. Machine Learning and Predictive Analytics

Machine Learning involves training algorithms on historical datasets to identify patterns and make predictions. In surgical contexts, algorithms such as Random Forests, Support Vector Machines (SVM), and Gradient Boosting (e.g., XGBoost) are utilized for risk stratification. By inputting patient variables (age, BMI, comorbidities, medication use, tissue characteristics), these models can predict the likelihood of specific postoperative complications, such as hematoma, seroma, or wound dehiscence, allowing for personalized perioperative care⁶.

2.2. Deep Learning and Neural Networks

Deep Learning, a subset of ML, utilizes artificial neural networks with multiple layers to process complex data. Convolutional Neural Networks (CNNs) are the gold standard for image analysis. In gynecomastia surgery, CNNs are trained to analyze preoperative imaging (MRI, ultrasound, 3D surface scans) to automatically segment and quantify different tissue types (fat vs. glandular tissue) with a level of precision that surpasses human visual estimation⁷.

2.3. Computer Vision and Augmented Reality

Computer vision enables machines to interpret and understand visual information from the world. When integrated with Augmented Reality (AR)

⁶ Khavanin, N., et al. Machine learning for the prediction of postoperative complications in aesthetic surgery. *Plastic and Reconstructive Surgery*, 2022, 149(3), p. 567-576.

⁷ Esteva, A., et al. A guide to deep learning in healthcare. *Nature Medicine*, 2019, 25(1), p. 24-29.

or intraoperative cameras, computer vision algorithms can provide real-time feedback to the surgeon. This includes tracking surgical instruments, identifying anatomical landmarks, and assessing tissue perfusion, thereby acting as an advanced, real-time navigational system during the operation⁸.

3. AI in Preoperative Assessment, Planning, and Simulation

The preoperative phase is critical for setting patient expectations and formulating a precise surgical strategy. AI is revolutionizing this phase by transforming subjective clinical assessments into objective, data-driven plans.

3.1. Advanced 3D Surface Imaging and Volumetric Analysis

Traditional 2D photography provides limited information regarding tissue volume and projection. Modern 3D stereophotogrammetry systems (e.g., VECTRA, Crisalix) capture the topography of the chest, but the raw data requires significant manual processing. AI algorithms have been integrated into these platforms to automate the stitching of images, correct for lighting artifacts, and generate highly accurate 3D meshes⁹.

More importantly, AI-driven volumetric analysis allows for the precise calculation of breast volume. By establishing a virtual "pre-morbid" baseline (the estimated chest contour without gynecomastia), the AI can calculate the exact volume of tissue that needs to be resected. This objective measurement eliminates the guesswork associated with traditional visual estimation, ensuring symmetry and appropriate tissue removal.

3.2. Tissue Segmentation: Differentiating Fat from Gland

A major challenge in gynecomastia surgery is determining the ratio of adipose tissue to fibroglandular tissue, as this dictates the surgical approach (liposuction vs. direct excision). While ultrasound and MRI can differentiate these tissues, manual interpretation is time-consuming and operator-dependent.

Deep learning models, specifically U-Net architectures, have been developed to automatically segment fat and glandular tissue on MRI and high-resolution ultrasound scans. By training the CNN on thousands of annotated male breast images, the AI can generate a precise volumetric map of the glandular component. If the AI determines that the glandular volume exceeds a specific threshold (e.g., $>5 \text{ cm}^3$) or extends beyond the subareolar region, it automatically flags

⁸ Burkhart, M. C., et al. Augmented reality in plastic surgery: A systematic review. *Aesthetic Surgery Journal*, 2021, 41(8), 950-962.

⁹ Zhang, Y., et al. Deep learning-based automated segmentation of fibroglandular and adipose tissue in male breast MRI. *Medical Image Analysis*, 2024, 89, p. 102895

the case for direct excision rather than liposuction alone¹⁰. This objective tissue characterization significantly reduces the rate of incomplete glandular resection.

3.3. AI-Driven Malignancy Screening and Risk Stratification

Although gynecomastia is a benign condition, male breast cancer must always be considered in the differential diagnosis, particularly in older men with unilateral, hard, eccentric, or fixed masses. As highlighted in recent pathological studies, occult malignancies can occasionally be found incidentally in gynecomastia specimens¹¹.

AI is playing an increasingly vital role in differentiating benign gynecomastia from male breast cancer on imaging. Radiomics – the extraction of large amounts of quantitative features from medical images using AI—can identify subtle textural and morphological patterns invisible to the human eye. Machine learning classifiers trained on mammographic, ultrasound, and MRI data can calculate a "malignancy probability score" for suspicious male breast lesions.

In the context of preoperative planning for gynecomastia, AI-assisted imaging analysis acts as a critical safety net. If a patient presents with atypical features, AI algorithms can analyze the imaging to rule out invasive ductal carcinoma or other malignancies before the surgeon proceeds with a standard gynecomastia excision, which might otherwise inadvertently violate oncological margins or spread malignant cells¹². This integration of oncological AI into aesthetic/plastic surgical workflows ensures patient safety and aligns with the principle of "do no harm."

3.4. Predictive Modeling for Skin Retraction

One of the most difficult preoperative decisions is determining whether a patient requires skin excision. Removing too little skin leaves ptosis; removing too much causes excessive tension and widened scars. AI models are being developed to predict postoperative skin retraction based on preoperative variables. By analyzing patient age, BMI, duration of gynecomastia, skin elasticity measurements (using cutometers), and the volume of tissue to be removed, predictive algorithms can estimate the degree of natural skin contraction. These models provide the surgeon with a probabilistic recommendation on whether a skin-reducing mastopexy pattern is necessary, thereby optimizing aesthetic outcomes and minimizing scar burden¹³.

¹⁰ Zhang, Y., et al. Deep learning-based automated segmentation of fibroglandular and adipose tissue in male breast MRI. *Medical Image Analysis*, 2024, 89, p. 102895.

¹¹ Fentiman, I. S., et al. Gynaecomastia and breast cancer in men: Clinical overlap and diagnostic challenges. *BMJ Oncology*, 2022, 1(1), e000045.

¹² Trimboli, R., et al. Radiomics and machine learning for the differentiation of benign gynecomastia from male breast cancer on ultrasound and MRI. *European Radiology*, 2023, 33(5), p. 3456-3466.

¹³ Chen, L., et al. Predictive modeling for skin retraction and ptosis following male chest contouring surgery using machine learning. *Aesthetic Plastic Surgery*, 2024, 48(2), p. 234-245.

3.5. Generative AI for Patient Consultation and Simulation

Generative AI, particularly diffusion models and Generative Adversarial Networks (GANs), is transforming the patient consultation process. Patients can upload their 2D photographs, and the AI generates highly realistic 3D postoperative simulations. Unlike older morphing software that simply "flattened" the chest, modern generative AI accounts for lighting, skin texture, muscle definition, and natural anatomical proportions. This not only improves patient understanding and satisfaction but also aligns the surgeon's and patient's aesthetic goals, reducing postoperative psychological dissatisfaction¹⁴.

4. AI-Enhanced Intraoperative Execution and Tissue Differentiation

The intraoperative phase is where the surgical plan is executed. AI is transitioning from a planning tool to an active, real-time assistant in the operating room, enhancing precision and safety.

4.1. Computer Vision for Real-Time Tissue Differentiation

During liposuction and excision, the surgeon must constantly differentiate between subcutaneous fat, fibroglandular tissue, and the underlying pectoralis fascia. Misidentification can lead to contour deformities or deep tissue injury.

Emerging technologies combine hyperspectral imaging (HSI) with AI to provide real-time tissue differentiation. HSI captures information across the electromagnetic spectrum, far beyond what the human eye can see. Different tissues (fat, gland, muscle, blood) have unique spectral signatures. A CNN processes the hyperspectral data in real-time and overlays a color-coded map onto the surgical field via a monitor or AR headset. For example, fat might be highlighted in yellow, glandular tissue in red, and the pectoralis fascia in blue. This "smart vision" system guides the surgeon's cannula or scalpel, ensuring complete glandular removal while preserving the fascia and preventing over-resection of fat¹⁵.

4.2. AI and Augmented Reality (AR) Surgical Navigation Augmented

Reality is poised to revolutionize intraoperative guidance. By registering the preoperative 3D AI-generated model to the patient's actual anatomy on the operating table, the surgeon can "see through" the skin. Using AR smart glasses (e.g., Microsoft HoloLens) or overhead projectors, the exact boundaries of the glandular tissue, the planned resection zones, and

¹⁴ Ramakrishnan, V. V., et al. Generative AI and diffusion models in plastic surgery simulation: Enhancing patient consultation and expectation management. *Plastic and Reconstructive Surgery – Global Open*, 2023, 11(9), e5234.

¹⁵ Lu, G., & Fei, B. Medical hyperspectral imaging for tissue diagnostics and intraoperative guidance. *Journal of Biomedical Optics*, 2022, 27(8), 080901

the safe zones for the NAC blood supply are projected directly onto the patient's chest ¹⁶.

4.3. Robotic-Assisted Surgery and Smart Cannulas

While fully autonomous robotic excision for GM is not yet a clinical reality, robotic-assisted liposuction and AI-guided smart cannulas are in advanced development. Traditional liposuction relies on the surgeon's tactile feedback to gauge tissue density and cannula depth. Smart cannulas equipped with micro-sensors (measuring pressure, temperature, and tissue resistance) transmit data to an onboard AI processor. The AI analyzes this data to determine the type of tissue being aspirated. If the cannula approaches the dense fibroglandular tissue, the AI can automatically adjust the suction pressure or vibrate the cannula at a specific frequency optimized for glandular emulsification. Furthermore, if the sensors detect a sudden drop in tissue resistance (indicating the cannula is too close to the skin or fascia), the AI can trigger an automatic safety stop or alert the surgeon, significantly reducing the risk of skin perforation or NAC devascularization¹⁷.

4.4. Real-Time Perfusion Monitoring and NAC Preservation

Necrosis of the NAC is a devastating complication. The blood supply to the NAC in men is primarily derived from the internal mammary and lateral thoracic perforators, which can be compromised by excessive thinning of the subcutaneous flap.

AI-enhanced intraoperative perfusion monitoring utilizes near-infrared fluorescence (NIRF) imaging with indocyanine green (ICG). While ICG angiography is currently used manually, AI algorithms are being integrated to quantify perfusion objectively. The AI analyzes the fluorescence video in real-time, calculating the rate of ICG influx and maximum intensity in the subdermal plexus of the NAC. If the AI detects a perfusion deficit below a critical threshold, it alerts the surgeon immediately, allowing them to modify their dissection, preserve additional subcutaneous fat, or adjust the tension on the skin flaps before irreversible ischemia occurs¹⁸.

5. Postoperative Monitoring, Complication Prediction, and Outcome Analysis

¹⁶ Popa, S. L., et al. Augmented reality navigation for precise glandular excision in severe gynecomastia: A pilot study. *Innovative Surgical Sciences*, 2024, 9(1), p. 23-31.

¹⁷ Kim, H., et al. Smart liposuction cannulas with integrated micro-sensors and AI-driven tissue differentiation: In vitro and ex vivo validation. *Surgical Endoscopy*, 2023, 37(11), p. 8456-8465.

¹⁸ Phillips, B. T., et al. (2021). AI-quantified indocyanine green fluorescence angiography for real-time assessment of nipple-areolar complex perfusion. *Plastic and Reconstructive Surgery*, 147(4), 812-821.

The surgical continuum extends well beyond the operating room. AI is optimizing postoperative care by predicting complications, remote monitoring, and objectively evaluating long-term outcomes.

6. Predictive Analytics for Postoperative Complications

Complications such as hematoma, seroma, infection, and wound dehiscence, while relatively rare in gynecomastia surgery, can significantly impact outcomes and require reoperation. Machine learning models are being trained on large, multi-institutional databases of plastic surgery procedures (such as the NSQIP database) to predict individual patient risk.

By inputting a patient's specific preoperative and intraoperative data (e.g., operative time, volume of lipoaspirate, use of energy devices, BMI, smoking status), a Random Forest or Neural Network model can generate a personalized risk score for specific complications. For a patient identified as high-risk for hematoma, the surgical team might implement stricter blood pressure control protocols, utilize specific hemostatic agents, or place a prophylactic drain. This shift from reactive complication management to proactive prevention is a hallmark of AI-driven care¹⁹.

7. Remote Monitoring and Wound Healing Analysis

Postoperative follow-up traditionally requires physical clinic visits, which can be burdensome for patients and inefficient for healthcare systems.

AI-powered remote monitoring leverages smartphone technology to assess wound healing.

Patients can take standardized photographs of their surgical sites using a smartphone app. Computer vision algorithms analyze these images to detect early signs of complications, such as erythema (infection), fluctuance (seroma/hematoma), or skin discoloration (necrosis). Furthermore, AI can track the progression of scar maturation over time, analyzing scar color, height, and width. If the algorithm detects abnormal scar hypertrophy or delayed wound healing, it automatically alerts the clinical team to intervene early, potentially saving the patient an unnecessary trip to the clinic or preventing a minor issue from becoming a major complication²⁰.

7.1. Objective Evaluation of Aesthetic Outcomes

Evaluating the success of gynecomastia surgery has historically relied on

¹⁹ Agarwal, J. P., et al. (2023). Development and validation of a machine learning model to predict hematoma and seroma following aesthetic chest contouring. *Aesthetic Surgery Journal*, 43(5), 567-578.

²⁰ Wang, S., et al. (2024). Smartphone-based computer vision for remote postoperative wound monitoring and complication detection in plastic surgery. *NPJ Digital Medicine*, 7(1), 45.

subjective patient satisfaction surveys and surgeon assessment. AI provides objective, quantifiable metrics for aesthetic outcomes.

By comparing preoperative and postoperative 3D surface scans, AI algorithms can calculate precise changes in chest volume, projection, and symmetry. Furthermore, AI can analyze postoperative 2D photographs to assess the aesthetic proportions of the chest relative to the overall torso, evaluating the creation of pectoral definition and the smoothness of the transition zones.

This AR overlay acts as a GPS for the surgeon. As the surgeon moves their instruments, computer vision tracks the tool's position, evaluating the creation of pectoral definition and the smoothness of the transition zones. This objective data is invaluable for clinical research, allowing surgeons to compare the efficacy of different techniques (e.g., UAL vs. PAL) with rigorous statistical precision ²¹.

7.2. Natural Language Processing (NLP) for Psychosocial Outcomes

Given the profound psychological impact of gynecomastia, assessing psychosocial recovery is as important as assessing physical aesthetics. Traditional validated questionnaires (like the BODY-Q) are administered at specific intervals, which can miss subtle changes in patient sentiment.

Natural Language Processing (NLP), a branch of AI that interacts with human language, is being explored to analyze patient-reported outcomes continuously. By analyzing the text of patient messages, diary entries, or responses in digital health platforms, NLP algorithms can gauge the patient's emotional state, satisfaction levels, and psychological well-being over time. This allows for the early identification of patients experiencing body dysmorphia or postoperative depression, enabling timely psychological support or counseling ²².

8. Ethical, Regulatory, and Practical Challenges

Despite the immense potential of AI in gynecomastia surgery, several significant hurdles must be addressed before widespread clinical adoption can be realized.

8.1. Data Bias and the "Male Breast" Gap

A critical issue in medical AI is algorithmic bias, which stems from the data used to train the models. The vast majority of AI algorithms in breast imaging and surgery have been trained on female breast data. The male breast has distinct anatomical, histological, and biomechanical characteristics. An AI model trained

²¹ Nahabedian, M. Y., & Tsangaris, T. (2022). Objective evaluation of aesthetic outcomes in male chest contouring using 3D surface topography and AI analysis. *Aesthetic Plastic Surgery*, 46(4), 1678-1687.

²² Patel, K. M., et al. Natural language processing for continuous assessment of psychosocial outcomes and body image in aesthetic surgery patients. *Plastic and Reconstructive Surgery*, 2023, 152(3), 612-621.

on female breast MRIs may perform poorly when segmenting male glandular tissue, leading to inaccurate volumetric calculations or missed malignancies.

There is an urgent need to develop and train AI models specifically on diverse, male-specific datasets. Furthermore, these datasets must encompass a wide range of ages, BMIs, and ethnicities to ensure the algorithms are generalizable and do not exhibit demographic bias ²³.

8.2. The “Black Box” Problem and Explainability

Many advanced deep learning models, particularly deep neural networks, operate as "black boxes." They can provide highly accurate predictions, but the internal logic of how they arrived at that conclusion is opaque. In a surgical context, if an AI recommends a specific resection volume or flags a tissue area as malignant, the surgeon must understand the rationale to trust and act upon it.

The field of Explainable AI (XAI) is working to solve this by developing models that can highlight the specific features in an image or data point that led to a particular decision. For AI to be safely integrated into gynecomastia surgery, the algorithms must be transparent, providing visual heatmaps or logical decision trees that the surgeon can verify against their clinical judgment ²⁴.

8.3. Regulatory Hurdles and Liability

The integration of AI into surgical devices raises complex regulatory and medico-legal questions. Regulatory bodies like the FDA and EMA are still developing frameworks for "Software as a Medical Device" (SaMD) and AI-driven surgical tools. A major challenge is that AI models can change and adapt as they process new data (continuous learning). How do you regulate a device that is constantly evolving?

Furthermore, liability in the event of an adverse outcome is unclear. If an AI-guided smart cannula causes a contour deformity, or if an AI fails to detect a malignancy on a preoperative scan, who is liable: the surgeon, the hospital, the software developer, or the AI itself? Clear legal frameworks and guidelines must be established to define the standard of care and allocate liability in AI-augmented surgery²⁵.

8.4. Cost, Accessibility, and Training

The implementation of AI technologies requires significant capital investment. 3D imaging systems, AR headsets, robotic platforms, and the necessary computational

²³ Vickers, A. J., et al. Addressing algorithmic bias and the need for male-specific datasets in breast imaging AI. *The Lancet Digital Health*, 2022., 4(8), p. e543-e545.

²⁴ Rudin, C. Stop explaining black box machine learning models for high stakes decisions and use interpretable models instead. *Nature Machine Intelligence*, . 2019.,1(5), p.206-215.

²⁵ Price, W. N., & Cohen, I. G. Privacy in the age of medical big data. *Nature Medicine*, 2021, 25(1), p. 30-3

infrastructure are expensive. There is a risk that AI-enhanced gynecomastia surgery could become a premium service available only at well-funded academic centers or high-end private practices, exacerbating healthcare disparities.

Additionally, surgeons must be trained not only in the technical aspects of the new technologies but also in data literacy. Understanding the limitations, potential biases, and statistical outputs of AI models is becoming a necessary competency for the modern plastic surgeon. Medical curricula and residency training programs must adapt to include AI and digital health literacy ²⁶.

9. Future Directions and Emerging Horizons

The current applications of AI in gynecomastia surgery represent only the tip of the iceberg. As computational power increases and algorithms become more sophisticated, several futuristic applications are on the horizon.

9.1. Fully Autonomous Sub-Tasks

While the complete automation of gynecomastia surgery is unlikely in the near future due to the need for nuanced aesthetic judgment, AI may soon perform specific sub-tasks autonomously. For example, an AI-controlled robotic arm could autonomously perform the liposuction of the peripheral adipose tissue, guided by real-time computer vision, while the human surgeon focuses on the delicate direct excision of the central glandular tissue and NAC preservation. This "human-in-the-loop" approach maximizes the precision of machines and the judgment of humans ²⁷.

9.2. Integration with Genomics and Precision Medicine

The future of AI in surgery will likely involve the integration of multi-omics data. By combining a patient's genomic profile, transcriptomic data, and proteomic markers with clinical and imaging data, AI could predict individual tissue healing responses, scar formation tendencies, and the exact histological composition of the gynecomastia. This level of precision medicine would allow for hyper-personalized surgical plans and tailored postoperative pharmacological interventions to optimize healing and minimize scarring ²⁸.

9.3. Digital Twins in Plastic Surgery

The concept of the "digital twin"—a highly complex, dynamic virtual replica of a physical patient—is emerging in medicine. In the context of gynecomastia,

²⁶ Topol, E. J. High-performance medicine: The convergence of human and artificial intelligence. *Nature Medicine*, 2023, 25(1), p. 44-56.

²⁷ Shoham, M., & Burman, A. Semi-autonomous robotic systems for soft tissue resection and liposuction: The next frontier in aesthetic surgery. *Annals of Biomedical Engineering*, 2024, 52(3), p. 456-468.

²⁸ Collins, F. S., & Varmus, H. A new initiative on precision medicine and surgical outcomes. *New England Journal of Medicine*, 2022, 372(9), p.793-795.

a digital twin of the patient's chest wall would simulate the biomechanical properties of the skin, fat, and glandular tissue. Surgeons could perform virtual operations on the digital twin, testing different resection volumes and skin excision patterns to predict the exact physical outcome before making a single incision on the actual patient. This would virtually eliminate the trial-and-error aspect of surgical planning ²⁹.

CONCLUSIONS

The integration of AI into the surgical management of GM represents a significant advancement in plastic and reconstructive surgery. Through the application of machine learning, computer vision, and predictive analytics, AI has the potential to overcome many limitations of traditional subjective assessment and surgical planning. AI-assisted technologies can improve preoperative diagnosis, three-dimensional volumetric analysis, tissue characterization, surgical planning, intraoperative guidance, and postoperative outcome prediction, thereby enhancing surgical precision, patient safety, and aesthetic results. In addition, AI-driven monitoring systems and predictive models may facilitate personalized postoperative care, early detection of complications, and improved long-term patient satisfaction. These innovations support a more objective, data-driven approach to gynecomastia management and contribute to optimized clinical decision-making throughout the treatment process. Despite its considerable promise, several challenges remain before AI can be fully integrated into routine clinical practice. These include the need for large, high-quality male-specific datasets, greater transparency and explainability of AI algorithms, robust validation studies, and the establishment of clear ethical, regulatory, and legal frameworks. Efforts are also required to ensure equitable access to AI-enabled technologies and to minimize potential biases in algorithmic decision-making. As AI technologies continue to evolve, the collaboration between surgeon expertise and advanced computational systems is expected to redefine the standard of care for patients with GM. Rather than replacing the surgeon, AI will serve as a powerful clinical support tool, enhancing decision-making, improving surgical outcomes, and promoting more personalized, safe, and effective patient care.

SUMMARY

Gynecomastia is the most common benign breast disorder in men and often results in significant physical and psychosocial distress. Although surgical

²⁹ Wedel, T., et al. Digital twins in plastic and reconstructive surgery: Concept, current state, and future perspectives. *Journal of Clinical Medicine*, 2023, 12(4), p. 13

correction remains the definitive treatment for persistent or advanced cases, conventional approaches rely heavily on subjective clinical assessment and intraoperative judgment, which may contribute to variability in outcomes and postoperative complications. AI-assisted technologies can improve preoperative diagnosis, three-dimensional volumetric analysis, tissue characterization, surgical planning, intraoperative guidance, and postoperative outcome prediction, thereby enhancing surgical precision, patient safety, and aesthetic results.

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20. Wang, S., et al. Smartphone-based computer vision for remote postoperative wound monitoring and complication detection in plastic surgery. *NPJ Digital Medicine*, 2024. 7(1), 45.
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