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Breast

Cadaveric Biomechanical Comparison of Prepectoral and Submuscular Implant-based Breast Reconstruction

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Summary: Decreased postoperative pain and functional impact have been associated with prepectoral breast implant placement versus submuscular placement; yet no mechanical analyses have quantified this difference. Using 1 postmortem human subject, a 3-dimensional biomechanical tracking system was used to determine the impact of pocket placement on shoulder girdle dynamics for submuscular acellular dermal matrix (ADM)–assisted and prepectoral implants. Smooth silicone breast implants were placed bilaterally—one in the prepectoral plane with anterior ADM coverage and the other in the submuscular ADM-assisted plane. Using tracking nodes at the sternum, clavicles, scapulae, and humeri, each shoulder was tested through serial standardized trials of extension, flexion, lateral extension/flexion, oblique extension/flexion, and abduction using manual manipulations of the shoulder and a counter-weight apparatus before and after implant placement. Bone kinematics (bony displacement and rotation) and kinetics (joint force and moment) were recorded. To achieve equal shoulder extension and flexion maneuvers, submuscular placement was associated with increased scapular, humeral, and clavicular displacement as well as increased scapular and humeral rotation compared with preoperative measurements, whereas prepectoral placement showed no difference. Increased scapular and clavicular rotation with extension and decreased rotation with abduction were noted with both pockets. This cadaveric biomechanical model shows that submuscular implant placement is associated with compensatory increases in bony displacements and rotation required to complete standardized movements consistent with activities of daily living. Further replication of this protocol with varying cadaveric body types and implant sizes would generate predicted postoperative shoulder movement models for implant-based breast reconstruction in different pocket locations. *(Plast Reconstr Surg Glob Open 2025;13:e6742; doi: 10.1097/GOX.0000000000006742; Published online 24 April 2025.)*

INTRODUCTION

Women are bombarded with decisions after a breast cancer diagnosis. Although some are dictated by the cancer itself, patient preference often plays a large role in the breast reconstructive path one chooses, ranging from autologous options such as the deep inferior epigastric artery perforator flap to implant-based reconstruction. Implant reconstruction remains by far the most popular choice for women, accounting for nearly 80% of all breast reconstructions annually.[1] Within the realm of implant reconstruction, one of the important decisions faced by the reconstructive surgeon is the placement of the implant above or below the pectoralis major muscle. Patient-specific factors such as mastectomy flap vascularity influence this decision intraoperatively. Decreased postoperative pain and functional impact have been associated with prepectoral breast implant placement,[2–5] whereas subpectoral implant placement has been demonstrated to

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Received for publication September 9, 2024; accepted March 14, 2025.

DOI: 10.1097/GOX.0000000000006742

Disclosure statements are at the end of this article, following the correspondence information.

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decrease long-term strength and range of motion, unless patients develop compensatory neuromuscular strategies.[6] Biomechanics testing has demonstrated little impact of subpectoral implants on shoulder stiffness or strength but worsened function after latissimus dorsi flap harvest and implant placement.[7,8] Prior work by Hojan and Manikowska[9] demonstrated that the weight of external breast prostheses does not affect functional body movements. However, scarce objective data on the impact of subpectoral versus prepectoral breast implant placement exist to educate both surgeons and patients on the impact of implant placement on physical well-being. To this end, this study was designed using an established cadaveric biomechanical model with a novel application to implant-based breast reconstruction.[10]

Takeaways

Question: Does the position of the breast implant above or below the pectoralis muscle affect postoperative motion and strength?

Findings: Using a cadaveric model with a 3-dimensional biomechanical tracking system, this study investigated the impact of breast implant placement on shoulder movement. The findings suggest that submuscular implant placement leads to greater compensatory movements during shoulder extension and flexion compared with preoperative measurements. Prepectoral implant placement showed less impact on shoulder movements, but still required some compensatory actions.

Meaning: The cadaveric model offers a valuable tool for comparing the biomechanical effects of breast implant placement, aiding future studies and improving patient education on reconstruction options.

METHODS

A single postmortem human subject (PMHS)—a 63-year-old woman weighing 45.4 kg and measuring 167.6 cm tall—was used to analyze various arm motions through instrumentation implanted on the sternum, scapulae, clavicles, and humeri (Fig. 1). Bilateral simple mastectomies were performed. Breast reconstruction was then completed with 350 cm^3 moderate plus profile smooth silicone breast implants, volume compatible with the mastectomy specimen, in the prepectoral position on the left breast with anterior acellular dermal matrix (ADM) coverage and in the submuscular ADM-assisted position on the right breast (Fig. 2). Shoulders were exercised before any testing with various repetitive motions. Two trials of manual rotation testing were then recorded for each shoulder before and after implant placement—abduction, flexion, extension, lateral flexion, and lateral extension. (**See Video [online]**, which shows a PMHS undergoing a manual abduction test of the right shoulder with white Vicon markers visualized as they move with the right upper extremity relative to the index markers.) Next, 2 trials of counter-weight rotation testing were recorded for each shoulder—oblique extension, oblique flexion, abduction, and flexion. All data were transferred to an anatomical global coordinate system based on the PMHS' spinal anatomy, as previously described.[10] The origin of the coordinate system was the T3 vertebra with z axis extending inferiorly to the L1 vertebra. The x axis was orthogonal to the y and z axes with positive values anteriorly. The y axis was orthogonal to the x and z axes with positive values to the right. Data from the left shoulder were mirrored to the right shoulder's reference frame to make the data comparable. Motion simulation graphs were created from the recorded joint forces, bony displacements, and bony rotations with each curve representing a single load-unload action. This model was evaluated to determine if the subpectoral and prepectoral positions of the implant would affect shoulder range of motion as a factor of its insertion on the humerus after crossing the glenohumeral shoulder joint.

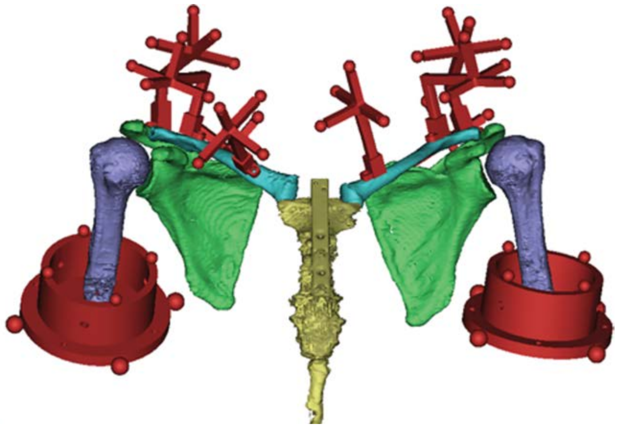

Fig. 1. Experimental setup. Motion tracking mounts on scapula (green) and clavicles (blue) and humeral mounts (purple) included both motion tracking nodes and a 6-axis load cell for the recording of kinematics and joint forces.

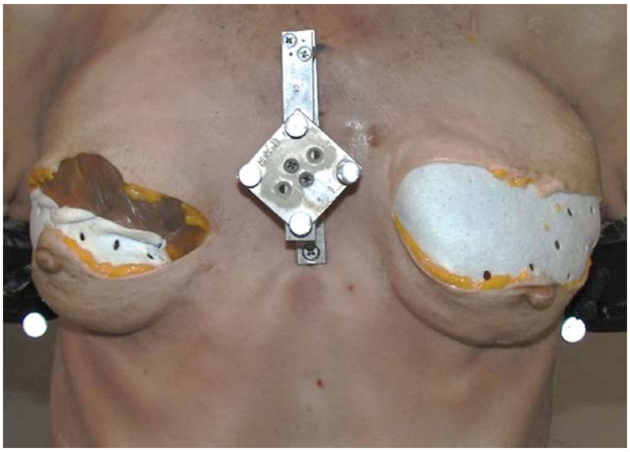

Fig. 2. Postmortem human subject surgery. Image taken after bilateral nipple-sparing mastectomies with partially submuscular, ADM-assisted coverage of the right breast implant and anterior support ADM coverage of the left prepectoral breast.

RESULTS

With the submuscular implant position, induced shoulder extension and lateral extension resulted in increased scapular, humeral, and clavicular displacement compared with preoperative shoulder rotation (Table 1). Similarly, shoulder extension and flexion maneuvers after submuscular implant placement resulted in greater scapular and humeral rotation than preoperative shoulder extension and flexion. These same shoulder movements performed after prepectoral implant placement were similar to the preoperative measurements for that shoulder.

Increased bony rotations of the scapula and clavicle were seen in the submuscular group when performing extension and lateral extension maneuvers compared with preoperative measurements. There was a decrease in scapular and clavicular rotation with abduction and oblique flexion in both implant groups when compared with preoperative control measurements.

A representative manual lateral extension maneuver image is shown in Figure 3. In this figure, maneuvers performed before and after prepectoral implant placement are superimposed, whereas the subpectoral implant postoperative maneuver shows a divergence from the preoperative curve as the maneuver is performed, demonstrating the increased displacement and rotation required for shoulder lateral extension.

Taken together, these findings suggest that implant placement in either plane may have an impact on shoulder function. After submuscular implant placement for breast reconstruction, greater compensatory sternal, scapular, clavicle, and humeral movements may be needed to achieve the same levels of shoulder extension and lateral extension, whereas greater scapular, humeral, and clavicular compensation may be required for shoulder flexion. Although fewer shoulder movements were impacted, prepectoral implant placement may require compensatory clavicular, humeral, and scapular movements for shoulder extension.

DISCUSSION

This cadaveric model is an innovative technique to define the biomechanical impact of breast implant placement above and below the pectoralis muscle, allowing for direct comparison of standardized movements performed pre- and postoperatively. The repeated measures before and after implant placement allow the subject's individual shoulder to serve as its own control. Varying implant size, method of ADM coverage, and PMHS habitus will build out the data on the performance of prepectoral and submuscular implant placement. Regarding cadaveric versus live patient biomechanics, we acknowledge that the lack of muscle tone, vascularity, and live tissue elasticity in cadavers does limit the direct extrapolation of these findings to a living population. However, the cadaveric model provides a controlled environment to isolate the impact of implant pocket placement on biomechanics using the PMHS as its own control, whereas live tissues' dynamic responses may vary. An additional area to apply the cadaveric model will be determining the impact of tissue expander placement above or below the pectoralis in staged implant-based reconstruction. Although previous studies have demonstrated the return of upper extremity function after implant placement, patient-reported quality of life does not recover to the same degree.[11,12] Ongoing refinement of techniques and a deeper understanding of various reconstruction methods remain essential to advancing the field of reconstructive surgery and enhancing outcomes for our patients.

CONCLUSIONS

Understanding the clinical implications of implant pocket selection is essential, as nearly 1 in 8 women will be diagnosed with breast cancer and may consider breast reconstruction options that align with their lifestyle needs and physical activity goals. This cadaveric analysis demonstrated greater bony compensatory motion required to complete standardized shoulder movements with a breast implant beneath the pectoralis muscle than when in a prepectoral plane. These findings may indicate that prepectoral implant placement preserves shoulder function more than subpectoral placement. With continued analysis using this model, shoulder motion data could help patients make more informed choices between

Table 1. Bony Compensatory Movements Resulting From Shoulder Manipulation After Submuscular ADM-assisted Implant Placement and Prepectoral ADM Anterior Support Implant Placement When Compared With Preoperative Control

Shoulder Input	Implant Location	Scapular Output	Humeral Output	Clavicular Output	Sternal Output
Extension	SM	↑ Displacement	↑ Displacement	↑ Displacement	↑ Displacement
		↑ Rotation	↑ Rotation	↑ Rotation	
Lateral extension	SM	↑ Displacement	↑ Displacement	↑ Displacement	↑ Rotation
		↑ Rotation	↑Rotation		
Flexion	SM	↑ Displacement	↑ Rotation	↑ Displacement	—
		↑ Rotation			
Oblique flexion	SM	↓ Rotation	—	↓ Rotation	—
Abduction	SM	↓ Rotation	—	↓ Rotation	—
Extension	PP	↑ Rotation	↑ Displacement	↑ Rotation	—
Lateral extension	PP	—	—	—	—
Flexion	PP	—	—	—	—
Oblique flexion	PP	↓ Rotation	—	↓ Rotation	—
Abduction	PP	↓ Rotation	—	↓ Rotation	—

PP, prepectoral ADM anterior support implant placement; SM, submuscular ADM-assisted implant placement; —, negligible difference when compared with preoperative measurements.

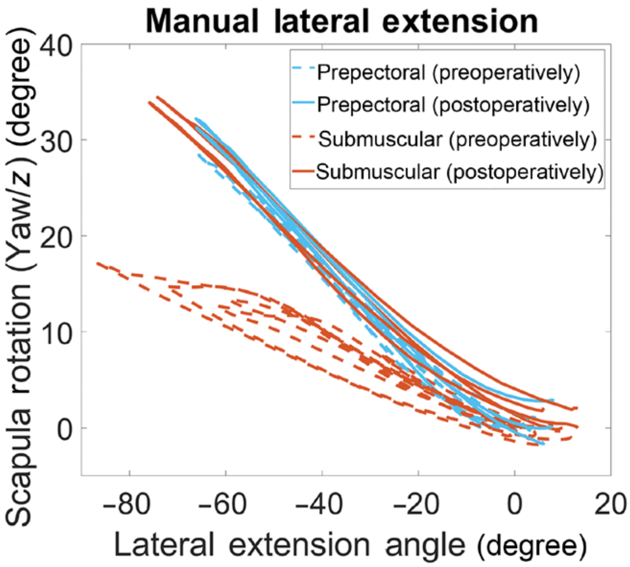

Fig. 3. Representative scapular rotation plot for the manual lateral extension test of the shoulder. With manual lateral extension of the shoulder, submuscular implant placement increases compensatory scapular rotation, as the dashed and solid red lines diverge through the maneuver, whereas prepectoral implant placement has no effect on these maneuvers, as the blue lines are superimposed pre- and postoperatively.

prepectoral and submuscular breast implant placement. Given the inherent limitations of our cadaveric study, future research efforts corroborating the impact of pocket selection on long-term shoulder biomechanics in living patients are needed.

For surgeons, the biomechanical data generated through cadaveric models offer an objective foundation to anticipate the functional impact of each implant type. By leveraging 3-dimensional biomechanical tracking, these models can simulate and predict postoperative shoulder mechanics, supporting clinical guidance that is responsive to patients' physical demands. This data-driven approach can also serve as a valuable patient education tool, allowing patients to visualize potential functional outcomes with each reconstructive approach, facilitating a more tailored and patient-centered decision-making process.

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DISCLOSURES

The senior author is a professional education speaker for Mentor and Integra. The other authors have no financial interest to declare in relation to the content of this article.

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