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Translating clinical expertise into feature selection for future peri-operative AI- based breast mass localization

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Article

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Abstract

Accurate localization of non-palpable breast tumors is a major challenge in breast-conserving surgery, because differences in patient position between preoperative imaging and surgery, together with breast mobility, anatomical variability and tissue deformation, may substantially alter tumor position. The clinically relevant, measurable factors that influence image-to-surgery breast tumor displacement (IS-BTD) have not been systematically established. We conducted a two-stage modified Delphi consensus among breast surgeons and breast-dedicated radiologists to identify factors perceived as influencing IS-BTD, supported by a focused literature review used to standardize terminology. The ranked features were then reviewed to retain those that were independent, measurable and reproducible. In total, 55 distinct features were identified, scored and ranked. Anatomical, positional and mechanical variables generally received higher weights than tumor-related characteristics; patient position received the highest weight (3.3), followed by breast ptosis (3.1) and breast size (3.0). This consensus provides a prioritized set of measurable features for investigating IS-BTD and a foundation for feature selection in future biomechanical and artificial intelligence-based models for perioperative breast tumor localization.

Introduction

As breast-conserving and oncoplastic breast surgery currently constitute the main surgical techniques for breast cancer (BC) treatment [1], and BC early detection prevails due to screening programs, resections of non-palpable tumors are performed increasingly [2]. Furthermore, the expanding indications for neoadjuvant systemic therapy, which subsequently lead to breast tumor shrinkage, have increased the need to excise a minimal tumor residue or just the tumor bed, localized by a marker placed in the tumor site before neoadjuvant treatment [2, 3]. Localization of non-palpable masses and markers constitutes one of the challenges in BC surgery, and a variety of methods have been developed for this purpose [2], including more recent artificial intelligence (AI)-based techniques [4].

As margin positivity is the most important cause of BC local recurrence [5], successful tumor resection with free margins is the surgeon's main target: consequently, accurate tumor localization is a major step in BC surgery [6]. However, a major challenge to this purpose is that the actual location of non-palpable tumors, as determined during surgery, may differ substantially from that assumed based on pre-operative images [7–9]. This is due to various reasons, including the different positions of the patient during mammography (patient upright, breast compressed between two plates in horizontal and oblique planes), sonography (supine or decubitus at varying degrees, arms in various positions), MRI (prone), and during surgery (most frequently supine, arms at 90 degrees). Also, the breast shape and positional state change substantially with changes in body position. On the other hand, breast manipulation during surgery affects tissues and causes structural deformities that can affect tumor location. Furthermore, breast shape and texture vary greatly among women, and one rule of tumor displacement cannot encompass all patients.

Biomechanical and AI modeling have been used to address this concern, and many researchers are seeking methods to predict or simulate the precise tumor location based on image-based computation combined with mechanical laws of tissue deformity; reinforced by machine learning protocols or neural networks [4, 10, 11] Regardless of the method used, the success of a simulation model depends on the availability of features that truly affect tumor displacement while they are measurable and reproducible, as an inconsistent input yields inaccurate predictions.. Nonetheless, these features have not still been recognized. Despite interesting novel techniques of AI-driven navigation in surgery [12, 13], the list and impact size of patient-,tumor-, biomechanical-, and imaging-derived factors that contribute to image-to-surgery breast tumor displacement (IS-BTD) remain not verified through consistent studies. Features as gravity and breast composition have been cited among effective factors [10, 14], but studies have mostly considered factors derived from the researchers' personal opinion, theoretical suggestions, or restricted retrospective information; instead of comprehensive, multidisciplinary surveys.

This study was designed as the first step of an AI-based breast surgery simulation project to systemically identify and score variables that affect IS-BTD based on the opinions and experience of dedicated radiology and surgery experts. The results will constitute the base for future pre-operative and intra-operative feature measurements and validation for prediction of breast tumor location.

Results

Expert Participants

The expert panel on the first round comprised 22 medical professionals, 13 breast surgeons and 9 breast-dedicated radiologists. Around two-thirds of professionals in each specialty (breast surgery, breast radiology) were experienced seniors (more than 20 years of subspecialty practice), and one-third were subspecialists who had recently graduated (within the last one to five years). All participants worked in high-volume centers for breast procedures, and thus managed a considerable number of patients with non-palpable breast tumors. Both Iranian and non-Iranian professionals were invited; the latter group responded virtually (Table 1).

Next, half of the experts were invited to take part in the second round, with the same distribution of experience levels. This same group finalized the sorted set of measurable features at the last meeting.

Table 1
Expert panel characteristics

Characteristic	Round 1 panel	Round 2 / final review panel
Total participants	22	11
Specialty composition	13 breast surgeons; 9 breast-dedicated radiologists	6 breast surgeons; 5 breast-dedicated radiologists
Professional background	Breast surgery and breast-dedicated radiology	Same professional groups
Experience profile	Approximately two-thirds senior experts (> 20 years) and one-third recently graduated subspecialists (1–5 years)	Same experience distribution reported
Clinical workload	All participants worked in high-volume breast centers and managed non-palpable breast tumors	Same panel subgroup
Selection criteria	Years of experience; breast workload; willingness to participate; nationality/geographic diversity	Same eligibility framework
Geographic participation	Iranian and non-Iranian experts; non-Iranian participants responded virtually	Same geographic pattern
Gender distribution	Surgeons: 4 male, 9 female, 0 non-binary; radiologists: 9 female	Surgeons: 3 men, 3 women, 0 non-binary; Radiologists: 4 women
Late/excluded response	Not applicable	One radiology form was returned late and eliminated

Finalized Features

A total of 55 distinct features were listed, scored and sorted on the final list. The highest scores were for patient position (3.3), breast ptosis (3.1), and breast size (3.0), and the lowest was for MRI quality (0.9). Table 2 shows all the mentioned features and their final weights (sorted). Supplementary Table S1 operationalizes these features as the final checklist of measurable variables, with their units of measurement or answer categories; several conceptual features (for example, tumor-to-skin distance) are listed separately for mammography, ultrasound, MRI and surgery because measurement techniques differ across these settings.

Table 2
List of all collected features recognized as affecting breast tumor displacement and their weights according to the expert panel.

Row	Priority	Domain	Feature	Weight
1	1	Patient positioning	Patient position	3.3
2	2	Breast anatomy	Breast ptosis	3.1
3	3	Breast anatomy	Breast size	3.0
4	4	Breast composition	Breast tissue composition (FGD)	2.6
5	4	Mammography/procedural	Breast compression during MG	2.6
6	4	Tumor presentation	Palpable vs. non-palpable lesion	2.6
7	4	Mammography/procedural	Breast positioning in MG	2.6
8	5	Imaging modality	Type of imaging modality	2.5
9	5	Patient positioning	Arm position	2.5
10	6	Tumor location/distances	Tumor-to-chest-wall distance	2.4
11	6	Operator/professional	Radiologist's expertise	2.4
12	6	Mammography/procedural	Degree of breast traction during MG	2.4
13	6	Tumor location/distances	Tumor location [1]	2.4
14	6	Ultrasound/procedural	Probe compression at US	2.4
15	7	Surgery/procedural	Intraoperative factors (traction, incision, manipulation)	2.3
16	8	Patient factors	Patient weight	2.2
17	8	Patient factors	Patient Height	2.2
18	8	Tumor location/distances	Tumor-to-skin distance	2.2
19	9	Tumor size/extent	Tumor size [2]	2.1
20	9	Operator/professional	Surgeon's expertise	2.1
21	10	Tumor fixation/invasion	Tumor fixation (to skin/chest wall/parenchyma)	2.0
22	10	Tumor location/distances	Tumor-to-nipple distance	2.0
23	10	Associated NML size	Size of accompanying NML	2.0

[1]Tumor location recorded as breast quadrant 2Tumor size recorded as the largest diameter or three-dimensional diameters. 3 Breast zones categorized as near, middle, and far zones. BMI= body mass index; FGD= fibro glandular density; MG= mammography; MRI= magnetic resonance imaging

Row	Priority	Domain	Feature	Weight
24	10	Associated microcalcifications size	Size of accompanying microcalcifications	2.0
25	10	Associated NML shape	Shape of accompanying NML	2.0
26	10	Associated microcalcifications shape	Shape of accompanying microcalcifications	2.0
27	10	Tumor microenvironment	Peritumoral fibrosis/inflammation	2.0
28	11	Tumor fixation/invasion	Chest wall fixation	1.9
29	11	Treatment history	Previous breast surgery	1.9
30	11	Measurement standardization	No standard measures for breast zones) [3]	1.9
31	12	Mammography/procedural	Breast thickness under compression	1.8
32	12	Tumor fixation/invasion	Skin invasion	1.8
33	12	Implants	Breast implant	1.8
34	12	Tumor size/extent	Number of tumors (unifocal/multicentric/multifocal)	1.8
35	12	Treatment history	Neoadjuvant chemotherapy	1.8
36	13	Breast anatomy	Breast thickness	1.7
37	14	Breast anatomy	Nipple position in relation to meridian line	1.6
38	14	Breast anatomy	Breast shape	1.6
39	14	Imaging/tissue morphology	Tissue distortion	1.6
40	14	MRI features	Tissue edema on MRI	1.6
41	14	Timing	Time interval between imaging and surgery	1.6
42	15	Tumor pathology	Tumor type (invasive/in-situ/benign)	1.5
43	15	Imaging morphology	Mass spiculation	1.5
44	16	Biomechanics	Gravity	1.3
45	16	Biomechanics	Skin stiffness	1.3
46	16	Tumor pathology	Tumor histology (ductal vs. lobular)	1.3

[1]Tumor location recorded as breast quadrant 2Tumor size recorded as the largest diameter or three-dimensional diameters. 3 Breast zones categorized as near, middle, and far zones. BMI= body mass index; FGD= fibro glandular density; MG= mammography; MRI= magnetic resonance imaging

Row	Priority	Domain	Feature	Weight
47	17	Ultrasound morphology	Mass circumference/margin sharpness at US	1.2
48	17	MRI features	Mass enhancement on MRI	1.2
49	18	Patient factors	Patient age	1.1
50	18	Mammography morphology	Mass density in MG	1.1
51	18	Tumor biomechanics	Tumor stiffness/elasticity	1.1
52	18	Patient factors	Menopausal status	1.1
53	19	Devices	Having port	1.0
54	19	Devices	Having pacemaker	1.0
55	20	MRI quality	Artifacts on MRI	0.9

[1]Tumor location recorded as breast quadrant 2Tumor size recorded as the largest diameter or three-dimensional diameters. 3 Breast zones categorized as near, middle, and far zones. BMI= body mass index; FGD= fibro glandular density; MG= mammography; MRI= magnetic resonance imaging

Discussion

Localization of non-palpable breast tumors based on spatial findings of pre-operative imaging is challenging because of the three-dimensional changes existing between imaging before surgery versus intraoperative reality. Refining breast mass localization using AI-based and biomechanical methods primarily relies on identifying features that affect IS-DBT. In this study, we collected experts' opinions on these features through two Delphi rounds. We finalized the list of weighted features based on consensus, retaining only independent, measurable, and reproducible factors. The final weighted feature set serves as a core for future real-world measurement and computation of the features' effects on IS-BTD.

The breast is an external body organ that is highly dependent on gravity; however, the degree of this dependency is highly variable among individuals, as breast weight, size, and shape alter breast mobility in various positions. Thus, both intra- and extra-breast anatomy affect the extent of change that occurs in breast placement, shape, and contour across various body positions. The key point is that the direction of the gravity vector varies substantially across different breast imaging studies and on the operating table. The changes encompass the transitions from erect to prone to supine positions, respectively used during mammography, MRI, and surgery; breast positioning and compression during mammography; and the patient position change for better visualization during breast ultrasound (from supine to semi-decubitus at various angles, arms up or down). These convey a very extensive range of changes in breast position, and consequently in tumor coordinates. Thus, measuring the distance of the

tumor center or margins from any anatomical landmark would not be consistent across procedures, including surgery.

The viscoelastic properties of the breasts depend on the ratio of fibroglandular to fatty tissue [15, 16], and the breast deformity occurring during compression or traction is very different in fatty versus dense breasts[14, 17].Accordingly, the extent of tumor displacement varies with these density variations, and the force applied during probe compression at sonography, plate compression during mammography; and traction, incisions, excisions, or pressures applied at surgery all exert different mechanical effects on the breast and the tumor. Moreover, fixation to or invasion of adjacent tissues affects the spatial configuration of the tumor.

Based on expertise, experience, and literature, these facts were considered during the expert panels. Consequently, mechanical factors as patient/arm position or breast compression during mammography, and anatomical factors like breast ptosis/size or breast tissue composition (ratio of fibroglandular tissue) were highly rated in the final list. The first and latter are in line with previous studies[10, 14], while the full list complements the recognized factors. On the other hand, some low-ranked factors on the list were unprecedented records in the existing literature. Future validation studies should estimate all these factors on real tumors to show their value.

This study has several strengths that merit notification. We followed a multidisciplinary approach in which the two groups of medical specialists involved in breast tumor localization, breast surgeons and breast radiologists, collaborated. Combining the extensive experience of senior experts with the up-to-date, more futuristic views of young subspecialists on AI-assisted medical practice ensured a wide range of perspectives. It offered a valuable, holistic view of the final consensus. Also, using a systematic consensus methodology, supported by a focused literature review, reduced the risk of bias while helping develop a comprehensive weighted feature list. Moreover, presenting only measurable and reproducible factors provided a ready-to-use final set of features for validation studies toward AI-assisted breast tumor localization.

Limitations of the study should also be considered. The weighting system assumed a linear relationship between each feature and IS-BTD, although some factors might be interrelated and have synergistic effects. Also, experts unintentionally assign higher scores to factors that they encounter more frequently, while some less common features may have a larger influence on IS-BTD. Finally, validation of the features and scores should be conducted in practice; the present list only provides the basis on which practical studies would rest. However, from an AI and computational modeling perspective, this collection of sorted variables is very valuable, as biomechanical simulations and AI models require appropriate input variables, and the present weighted feature set could serve as basic input.

Localization of non-palpable breast tumors based on pre-operative assessment is a clinical challenge due to the spatial changes that occur between imaging and surgery. This two-stage consensus process involving breast surgeons and radiologists systematically identified and assigned weights to 55 measurable features affecting IS-BTD. The outcome showed higher scores for anatomical and

mechanical factors, including patient/arm position, breast size, ptosis, and tissue composition, compared to tumor characteristics. Finally, practical validation of the finalized weighted list will provide a basis for selecting features in future artificial intelligence algorithms, thereby improving oncological outcomes.

Methods

Study Settings and Design

This is the first phase of a study designed for the detection of factors that affect IS-BTD. The study was approved by the Ethics Committee of Tehran University of Medical Sciences, Tehran, Iran (Ethics Approval Code: IR.TUMS.IKHC.REC.1405.085). A two-stage modified Delphi approach was followed to reach expert consensus on factors affecting IS-BTD and their weights. All methods were performed in accordance with the relevant guidelines and regulations, including the Declaration of Helsinki.

Participants

The expert panel comprised breast surgeons and breast-dedicated radiologists. Criteria for the selection of these professionals were four-fold: 1. Years of experience, to get advantage from both the expert opinion of senior professionals and the up-to-date view of junior subspecialists; 2. Breast workload, to be familiar with the approaches to non-palpable breast tumors; 3. Desire to participate; 4. Nationality: to encompass various geographic settings. None of the participants received financial compensation for participation, and no financial conflicts of interest related to this Delphi process were declared. Informed consent was obtained from all participating experts prior to their participation: experts based in Iran provided written informed consent on a signed consent form, and experts based outside Iran provided informed consent by e-mail. No patients, patient data or patient images were involved in this study. Some of the authors (S.A, M.K, A.S, N.A) are breast surgeons or breast-dedicated radiologists who met the same selection criteria and therefore also served as panelists; they completed the questionnaires in the same way as the other experts, and their responses were pooled and weighted identically.

Collection of Features, Consensus Rounds

We used structured open-ended questionnaires for the first round. After an educational session, all participants were asked to list the features they thought could affect IS-BTD, and mark their suggested impact severity on a five-point scale, (very low, low, medium, high, and very high). The questionnaire for the radiologists included three sections: for mammography, breast ultrasound, and breast MRI.

Meanwhile, a systematic literature review was conducted to extract all the features reported to affect IS-BTD, for consideration in the next Delphi round.

Then, all variables cited by the panel were extracted, organized after deleting duplicates and renaming similar features, and converted to tabular format showing the total count for each score level (very low

to very high) for each variable. No additional features were found in the literature review, but the results were used to ensure the consistent use of variable terminology.

The table was presented to all panelists in the second round, and each allocated their final score to every variable while noting the set of scores assigned by their colleagues in the first round. In this phase, six impact levels were offered: no impact (0), very low (1), low (2), medium (3), high (4), and very high (5) impact of the feature on IS-BTD. The flowchart of the consensus steps is illustrated in Fig. 1

Figure 1: overview of the modified Delphi process used in this study

IS-BTD: Image-to-surgery breast tumor displacement

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Final Score Analysis

To compute the final score for each feature, a value from 0 to 5 was respectively assigned to the 6 Likert scores (from no impact to very high impact), and the count of each was multiplied by that value; the average of the six returned products for each variable (multiplied by 100 and rounded to one decimal place) constituted the final score (coefficient or weight) for that feature; as demonstrated in the formula below.

$$W_F = \frac{\sum V_L \times C_L}{N} \times 100$$

Where W is the weight of each feature (F), V is the value assigned (0–5) to the 6 Likert (L) choices (no impact to very high impact), C is the count of that value, and N is the number of participants who have scored that feature.

At that point, the features were ranked from the most to least effective based on their final calculated weights. Thereafter, to develop a weighted list of features for future practical studies, the sorted list was evaluated in a panel of breast radiologists and surgeons. Variables that were deemed not measurable or not reproducible on imaging systems or clinically, and those that were dependent on other mentioned variables and were not effective per se were removed. The final sorted, weighted set of features was developed.

Declarations

Competing interests

The authors declare no competing interests.

Use of generative AI

Generative AI tools were not used for study design, data analysis, interpretation of results or scientific decision-making.

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Author Contribution

S.A. conceived the study, coordinated the Delphi panel, and contributed to writing the manuscript. R.O. contributed to conceptualization and the Delphi process. N.R.R. was responsible for the artificial intelligence-related aspects and edited the manuscript. N.A. coordinated the Delphi process and contributed to the design of the questionnaires and to the radiology-related aspects. A.S. developed the scoring formulation and performed the scoring analysis. M.K. drafted the manuscript, coordinated the study, and served as corresponding author. All authors reviewed and approved the final manuscript.

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Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

References

1. Wazir, U. & Mokbel, K. Oncoplastic breast-conserving surgery: advancing oncological outcomes and aesthetic standards in breast cancer treatment. *Gland Surg.* **14**, 797–799 (2025).
2. Cheung, B. H. H., Lui, T. T. N. & Kwong, A. Evolution of localization methods for non-palpable breast lesions: a literature review from a translational medicine perspective. *Transl Breast Cancer Res.* **5**, 12 (2024).

3. Jha, C. K. et al. Does tumor marking before neoadjuvant chemotherapy helps achieve better outcomes in patients undergoing breast conservative surgery? A systematic review. *Indian J. Surg. Oncol.* **12**, 624–631 (2021).
4. Hirsch, L. et al. High-performance open-source AI for breast cancer detection and localization in MRI. *Radiol. Artif. Intell.* **7**, e240550 (2025).
5. Bundred, J. R. et al. Margin status and survival outcomes after breast cancer conservation surgery: prospectively registered systematic review and meta-analysis. *BMJ* **378**, e070346 (2022).
6. Jong, L. J. S. et al. Toward real-time margin assessment in breast-conserving surgery with hyperspectral imaging. *Sci. Rep.* **15**, 9556 (2025).
7. Amano, M. et al. Association between patient position-induced breast shape changes on prone and supine MRI and mammographic breast density or thickness. *Jpn J. Radiol.* **43**, 641–648 (2025).
8. Alfano, F. et al. Breast tumor localization by prone to supine landmark driven registration for surgical planning. *IEEE Access.* **10**, 122901–122911 (2022).
9. Wang, C. B. et al. Breast tumor movements analysis using MRI scans in prone and supine positions. *Sci. Rep.* **10**, 4858 (2020).
10. Wang, K. & Kesavadas, T. Real-time FEA-based breast deformation simulation using artificial neural network. *Comput. Methods Programs Biomed. Update*. **2**, 100052 (2022).
11. Mahichi, H. et al. BreastCNet: breast cancer detection, classification, and localization convolutional neural network with advanced optimization techniques. *IEEE Access* (2025).
12. Gorgy, A. et al. Integrating AI into breast reconstruction surgery: exploring opportunities, applications, and challenges. *Plast. Surg.* **34**, 37–46 (2026).
13. Yizhuo, S. et al. Artificial intelligence in breast reconstruction. *Artif. Intell. Surg.* **5**, 150–159 (2025).
14. Goodbrake, C. et al. On the three-dimensional mechanical behavior of human breast tissue. *Ann. Biomed. Eng.* **50**, 601–613 (2022).
15. Teixeira, A. M. & Martins, P. A review of bioengineering techniques applied to breast tissue: mechanical properties, tissue engineering and finite element analysis. *Front Bioeng. Biotechnol* **11** (2023).
16. Ramião, N. G. et al. Biomechanical properties of breast tissue, a state-of-the-art review. *Biomech. Model. Mechanobiol.* **15**, 1307–1323 (2016).
17. Szumiejko, A., Ptak, M. & Dołęga-Kozierowski, B. Computational methods in breast cancer diagnostics and surgery planning: a review. *Arch. Comput. Methods Eng.* **33**, 3391–3423 (2026).

Figures

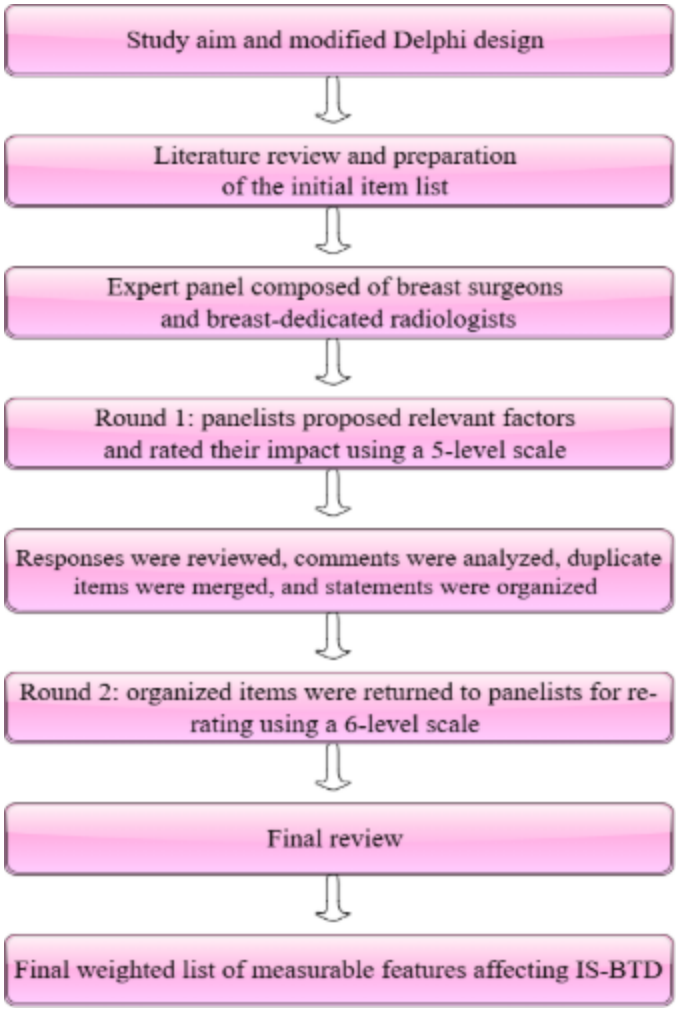


Figure 1

overview of the modified Delphi process used in this study

IS-BTD: Image-to-surgery breast tumor displacement

Supplementary Files

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- Supplementary.docx