

RESEARCH

Open Access



A 3D-printed screw mechanism as an alternative method to prevent wire migration in nonpalpable breast lesion localization

Iksan Tasdelen¹ , Adnan Gundogdu^{2*} , Kaan Celik³ , Osman Cem Yilmaz⁴ and Levent Celik⁵

Abstract

Background Wire localization for nonpalpable breast lesions and pre-neoadjuvant chemotherapy (NAC) clips can lead to complications including wire migration, pneumothorax, and organ injury. This study evaluates the clinical efficacy and safety of a novel 3D-printed screw mechanism designed to prevent wire migration.

Methods This retrospective descriptive study included 104 patients with nonpalpable breast lesions and pre-NAC clips who underwent wire localization between March 2023 and August 2024. A screw mechanism was designed and manufactured using 3D printing technology with polylactic acid (PLA) material (4 g per device). The device features a 21.7 mm base diameter and elliptical wire hole (2.5 × 4 mm). Wire stability and complications were assessed through imaging and clinical follow-up.

Results The median age was 47 years (range: 33–82) and median BMI was 24.7 (17.9–40.8). Lesions were primarily located in the upper outer quadrant (49.9%). Among 68 patients receiving NAC, 44.1% achieved pathological complete response (ypT0N0). The screw mechanism successfully prevented wire migration during patient transport from radiology to operating room in all 104 cases (0% migration rate, 95% CI: 0–3.6%). No complications including pneumothorax, organ injury, or skin reactions were observed. The device was easily removed by simple unscrewing on the operating table before surgical skin preparation. Median device application time was 2–4 h.

Conclusion The 3D-printed screw mechanism effectively prevents wire migration and demonstrates excellent safety profile. Its simple design and ease of application make it a practical solution for improving patient safety during breast lesion localization procedures.

Trial registration Not applicable. This retrospective study did not require trial registration.

Keywords Wire migration, Breast surgery, Nonpalpable lesion localization, Screw mechanism, Surgical stabilization

*Correspondence:

Adnan Gundogdu
adnangundogdu89@gmail.com

¹Fatih Sultan Mehmet Eğitim ve Araştırma Hastanesi, Istanbul, Turkey

²Sancaktepe Şehit Prof. Dr. İlhan Varank Eğitim ve Araştırma Hastanesi, Emek Mahallesi, Namık Kemal Cad. No:54, 34785 Sancaktepe, İstanbul, Türkiye

³University of Naples Federico II, Naples, Italy

⁴Istanbul Breast Center, Istanbul, Turkey

⁵Radiologica Imaging and Diagnosis Center, Istanbul, Turkey



© The Author(s) 2025. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

Introduction

Wire localization is the most commonly used technique in breast surgery for the surgical excision of nonpalpable breast lesions and for guiding surgery after marker clip placement prior to neoadjuvant chemotherapy (NAC), with a majority of units worldwide still relying on this method [1, 2]. As the diagnosis of nonpalpable breast cancers has increased, wire localization guided by mammography and ultrasonography has become increasingly common. This technique accurately localizes tumors, spares uninvolved breast tissue, and enhances the precision of breast-conserving surgery. Although wire localization is generally well-tolerated, it is not without complications. Common issues include bleeding, pain, premature wire removal, and vasovagal reactions. More serious, albeit rarer complications, such as wire fragmentation, migration, pneumothorax, pleural migration, and tumor seeding also pose risks [3, 4].

Wire migration, in particular, presents a significant challenge during patient transport from radiology to the operating room. When wires move from their intended position during this critical period, surgical accuracy is compromised, complicating the procedure. This can lead to difficulties in intraoperative wire tip assessment, which may result in incomplete excisions or the unnecessary removal of healthy tissue [4]. The risk of migration is particularly high during patient positioning, transport, and preparation phases before surgery begins.

Recent meta-analyses have provided valuable data on wire migration rates and alternative localization methods. Shirazi et al. (2023) conducted a comprehensive pooled analysis comparing wire and non-wire localization techniques, demonstrating that non-wire methods had lower positive margin rates compared to traditional wire localization [4]. Additionally, the iBRA-NET study, one of the largest multicenter analyses, documented wire dislodgement in 1.4% of 1,170 wire-guided procedures [5].

Despite the existence of alternative localization techniques such as magnetic seeds (Magseed), radiofrequency identification tags (LOCALizer), radioactive seed localization, and radar reflectors (SAVI Scout), wire localization remains the predominant method. While these wire-free alternatives offer advantages including flexible scheduling, elimination of migration risk, and improved patient comfort, they face significant limitations including requirement for specialized detection equipment, limited availability especially in resource-constrained settings, and learning curves for both radiologists and surgeons [6, 7]. The complications associated with wire localization and the economic burden from re-excisions underscore the need for enhancements to this technique that maintain its accessibility, rather than

complete replacement with alternatives that may not be readily available in all clinical settings.

This study introduces an innovative screw mechanism designed to prevent wire migration during breast lesion localization. The mechanism aims to enhance wire stability by preventing both forward and backward movement through a simple mechanical design. Our goal is to assess the efficacy and safety of this newly developed screw mechanism in clinical settings, demonstrating its potential as a practical, cost-effective solution that improves patient safety while maintaining the familiarity and accessibility of traditional wire localization techniques.

Materials and methods

Study design

This retrospective descriptive study was conducted between March 2023 and August 2024 to evaluate the effectiveness of a newly developed screw mechanism designed to prevent wire migration during breast lesion localization.

Patient selection

We assessed 128 consecutive patients, of which 104 patients with nonpalpable breast lesions or clips placed before neoadjuvant chemotherapy (NAC) were included in the study.

The inclusion criteria were as follows:

- Nonpalpable breast lesion requiring localization.
- Age greater than 18 years.
- Scheduled for breast-conserving surgery.

We excluded patients who met any of the following conditions:

- Multicentric/multifocal disease ($n=9$).
- Diffuse microcalcifications ($n=6$).
- Preference for mastectomy ($n=5$).
- Advanced disease ($n=2$).
- Disease progression during NAC ($n=2$).

For clarity, multifocal disease was defined as having two or more tumor foci within the same quadrant, whereas multicentric disease involved tumor foci in different quadrants or separated by more than 5 cm.

Design of the screw mechanism

The screw mechanism was developed to prevent wire migration through a simple mechanical design. It consists of two main components:

1. **Screw Body:** This component includes a cap that provides firm tissue support, thus preventing any forward or backward movement of the wire. The

design specifications include a base diameter of 21.7 mm and a total height of 16.8 mm (see Fig. 1). The selected base diameter was intended to distribute pressure over a wide area to minimize tissue compression effectively.

2. Cover Mechanism: This part secures the wire to the screw body via a locking system. The cover is

designed with an elliptical hole measuring 2.5×4 mm, allowing for unobstructed wire accommodation while preventing slippage. Detailed technical specifications are displayed in Fig. 1. In the cross-sectional view (A-A), the path of the wire as it curves through the top hole and exits through the bottom

Design Specifications of the Screw Mechanism

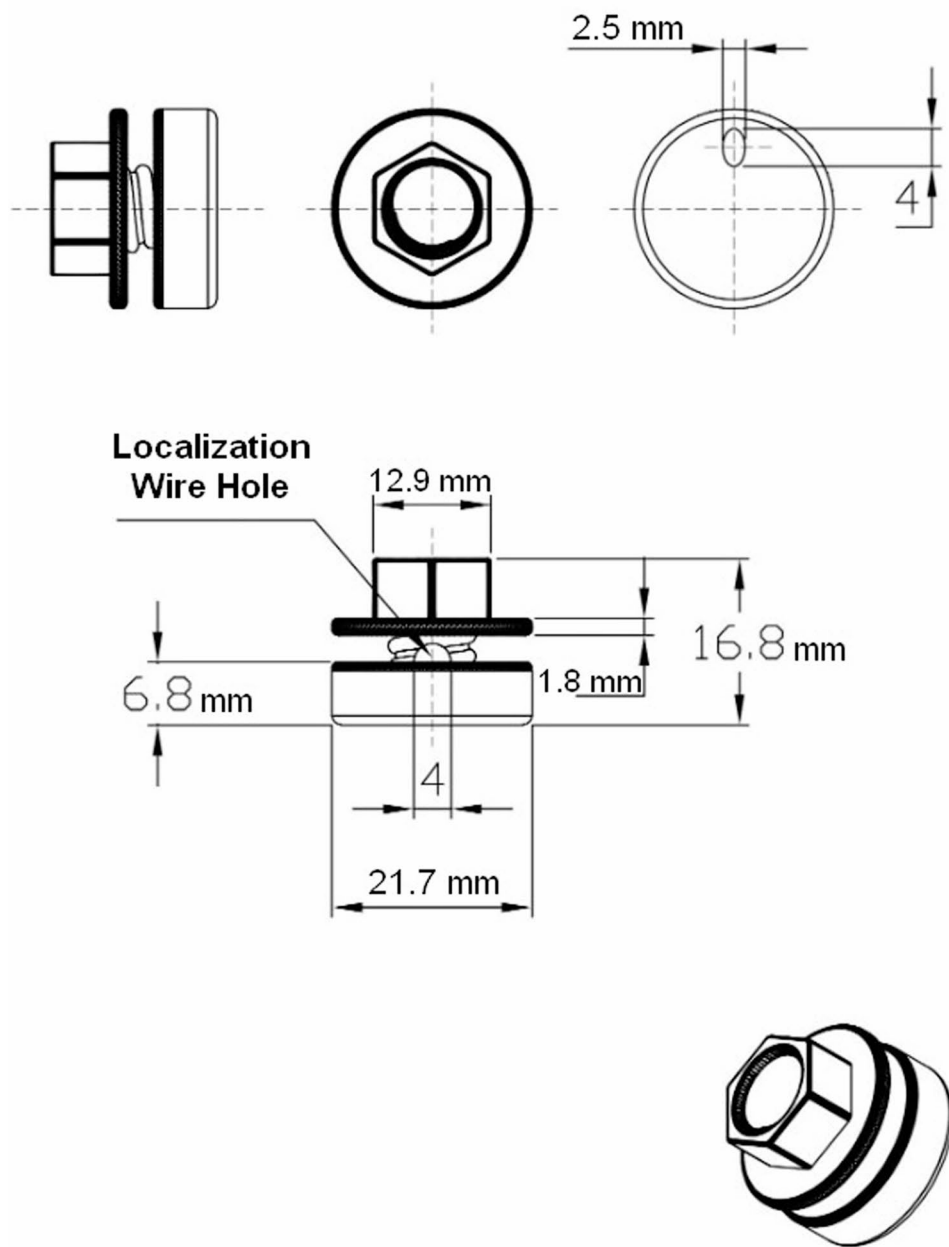


Fig. 1 Design specifications of the screw mechanism. Technical specifications of the 3D-printed screw mechanism showing key dimensions: base diameter (21.7 mm), elliptical wire hole (2.5×4 mm), total height (16.8 mm), and threading system. The elliptical design prevents wire obstruction during removal

hole is depicted, illustrating how the design secures the wire in the desired position (see Fig. 2).

Manufacturing specifications

The device was manufactured using Fused Deposition Modeling (FDM) 3D printing technology (illustrated in Fig. 3), primarily utilizing polylactic acid (PLA), a biopolymer derived from renewable resources. PLA is a non-toxic thermoplastic known for its environmentally friendly properties, making it suitable for medical applications. It is widely used in various fields, including food packaging, healthcare, structural applications, textiles, and cosmetics [8].

Manufacturing parameters

- Layer resolution: 0.2 mm.
- Infill density: 30%.
- Print temperature: 200 °C (nozzle), 65 °C (bed).
- Print speed: 45 mm/s.
- Material usage: 4 g PLA per device.
- Applied force: approximately 0.04 N (equivalent to 4 g weight).

Sterilization protocol

All screw components underwent sterilization using ethylene oxide. This sterilization method was selected considering the device's single-use application during patient transport and its removal before establishment of the surgical sterile field.

Cost analysis

The production cost per device is approximately \$1, broken down as follows:

- PLA material (4 g): \$0.30.

- 3D printing time (24 min): \$0.40.
- Ethylene oxide sterilization: \$0.30.

A utility model patent application has been filed with the Turkish Patent and Trademark Office (Application Number: TR 2023 018924, Filing Date: 27.12.2023).

Clinical application

After a thorough evaluation by a multidisciplinary tumor board and preoperative imaging (mammography, ultrasonography, and selective MRI), the localization procedure was performed as (Fig. 4):

1. The surgical approach and incision site were determined by the multidisciplinary tumor board based on tumor location, size, and cosmetic considerations.
2. The localization wire was inserted into the target lesion under ultrasound guidance.
3. The wire was threaded through the screw mechanism's elliptical hole.
4. The screw was positioned against the skin and tightened to secure the wire.
5. The screw mechanism prevents wire migration by mechanically fixing the wire at the skin entry point during patient transport from radiology to operating room.
6. The device was easily removed by gentle unscrewing on the operating table immediately before surgical skin preparation and draping, without applying force or causing wire displacement.
7. The elliptical hole design (2.5 × 4 mm) allows smooth wire release during device removal without tension or pulling forces on the wire.
8. Maximum application time was limited to 4 h before surgery.

A-A View of the Screw Mechanism

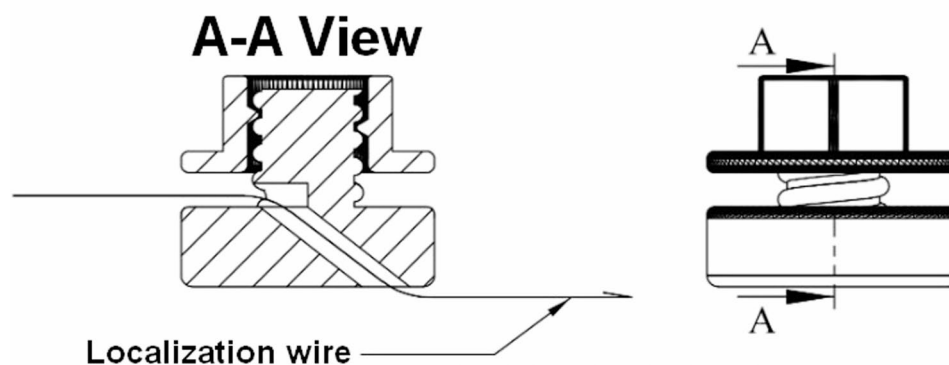


Fig. 2 A-A View of the screw mechanism. Cross-sectional view demonstrating the wire path through the mechanism. The wire enters through the top, curves through the elliptical channel, and exits at the bottom, secured by the threaded locking system



Fig. 3 Production of screw mechanism components. 3D printing manufacturing process using FDM technology with PLA material. Shows the ANYCUBIC printer setup and finished devices ready for sterilization and clinical use

9. Skin assessment was performed before and after device removal to monitor for pressure-related changes.
10. Intraoperative ultrasound was used to ensure complete tumor excision with negative margins.

Statistical analysis

This was a descriptive study without a control group. Data were analyzed using R version 4.3.0. Descriptive statistics were presented as median (range) for continuous variables and n (%) for categorical variables. The 95% confidence interval for the zero wire migration rate (0/104) was calculated using the Wilson score method with the 'binom' package in R, yielding 95% CI:

0-3.6%. Due to the descriptive nature of the study and the absence of complications, comparative statistical tests and p-value calculations were not applicable.

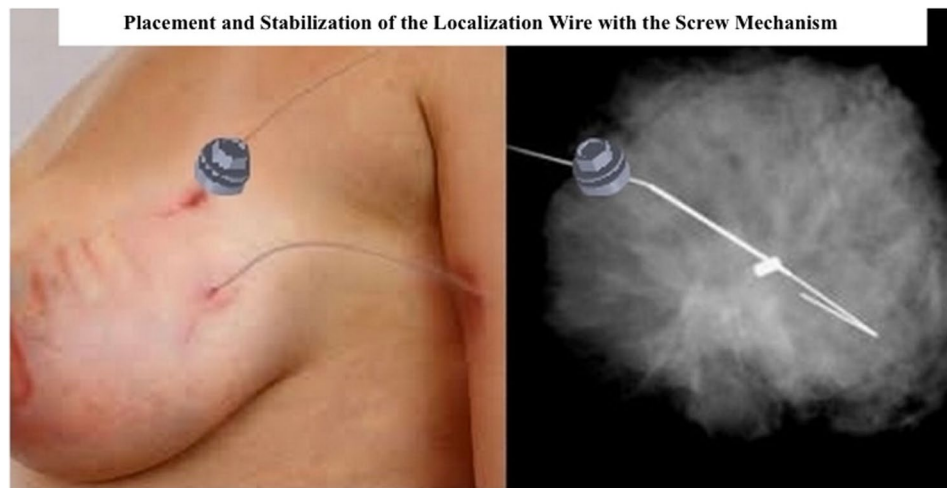
Ethical approval

The study protocol was approved by the Ethics Committee of Sancaktepe Şehit Prof. Dr. İlhan Varank Training and Research Hospital (Approval Number: 2024/294, Date: 18.09.2024).

Results

Patient characteristics

A total of 104 patients underwent wire localization using the screw mechanism. The median age was 47 years



The localization needle is placed in the suspicious area under ultrasound guidance. Then the needle is pulled back, leaving the wire inside. Part of the wire remains inside the breast, while the other part stays outside. The outer part is fixed to the wire holder, and the cap part of the product is tightened with a wrench to prevent the wire from moving inward.

Fig. 4 Placement and stabilization of the localization wire with the screw mechanism clinical application demonstrating (left) screw mechanism positioned on patient skin securing the localization wire, and (right) mammographic view showing wire placement within breast tissue

Table 1 Demographics and clinical characteristics of the patients

Variable		All Patients (n = 104)
Age (median, min-max)		47 (33–82)
BMI (median, min-max)		24.7 (17.9–40.8)
Side	Left	70 (67.3)
	Right	34 (32.7)
Lesion quadrant	Upper Outer Quadrant (UOQ)	52 (49.9)
	Upper Inner Quadrant (UIQ)	16 (15.4)
	Central	14 (13.5)
	Lower Outer Quadrant (LOQ)	8 (7.7)
	Lower Inner Quadrant (LIQ)	
Multisentric/Multifocality	Absent	90 (86.5)
	Present	14 (13.5)
Axillary marking	Absent	100 (96.2)
	Present	4 (3.8)
Preoperative pathology	IDC	56 (53.8)
	ILC	6 (5.8)
	Mixed (ILC & IDC)	4 (3.8)
	Tubular Carcinoma	2 (1.9)
	DCIS	14 (13.6)
	LCIS	2 (1.9)
	Benign	20 (19.2)

BMI Body Mass Index, IDC Invasive Ductal Carcinoma, ILC Invasive Lobular Carcinoma, DCIS Ductal Carcinoma In Situ, LCIS Lobular Carcinoma In Situ

(range: 33–82 years), and the median body mass index (BMI) was 24.7 kg/m² (range: 17.9–40.8). Lesion distribution by quadrant was as follows: upper outer (49.9%), upper inner (15.4%), central (13.5%), lower outer (13.5%), and lower inner (7.7%). Multisentric/multifocality disease was observed in 14 patients (13.5%). Preoperative pathology revealed invasive ductal carcinoma (IDC) in 56 patients (53.8%), benign findings in 20 patients (19.2%), ductal carcinoma in situ (DCIS) in 14 patients (13.6%), invasive lobular carcinoma (ILC) in 6 patients (5.8%), and mixed carcinoma (ILC and IDC) in 4 patients (3.8%) (Table 1).

Neoadjuvant chemotherapy subgroup

Among the 68 patients who received neoadjuvant chemotherapy, the median age was 48 years (range: 33–82) and the median BMI was 25.5 kg/m² (range: 17.9–40.8). Clinical staging showed T1N1 as the most common presentation (29.4%), followed by T2N1 (23.5%) and T2N0 (20.6%). Most lesions were located in the upper outer quadrant (47.1%), and 20.6% had multifocal disease. The median pre-NAC lesion size was 1.9 cm (range: 0.5–4.6 cm). Following NAC, a pathological complete response (pCR) was achieved in 30 patients (44.1%), while 38 patients (55.9%) had residual disease. The predominant molecular subtype was luminal B (44.1%), followed by luminal A (26.5%), HER2-positive (17.6%), and triple-negative (11.8%) (Table 2).

Table 2 Demographics and clinical characteristics of the patients who received neoadjuvant chemotherapy

Variable		Patients (n = 68)
Age (median, min-max)		48 (33–82)
BMI (median, min-max)		25.5 (17.9– 40.8)
Lesion quadrant	Upper Outer Quadrant (UOQ)	32 (47.1)
	Upper Inner Quadrant (UIQ)	12 (17.6)
	Central	10 (14.7)
	Lower Outer Quadrant (LOQ)	4 (5.9)
	Lower Inner Quadrant (LIQ)	
Lesion size (cm) (median, min-max)		1.9 (0.5–4.6)
Multicentric/Multifocality	Absent	54 (79.4)
	Present	14 (20.6)
cTN stage	T1N0	10 (14.7)
	T1N1	20 (29.4)
	T2N0	14 (20.6)
	T2N1	16 (23.5)
	T2-3N2-3	8 (11.8)
Pathological response	Complete response (pCR)	30 (44.1)
	Residual disease	38 (55.9)
Molecular subtype	Luminal A	18 (26.5)
	Luminal B	30 (44.1)
	HER2 - positive	12 (17.6)
	Triple-negative	8 (11.8)

BMI body mass index, cm centimeter, cTN clinical tumor-node stage, NAC neoadjuvant chemotherapy, pCR pathologic complete response, HER2 human epidermal growth factor receptor 2

Wire migration

No wire migration occurred in any of the 104 patients (0%, 95% CI: 0–3.6%). Intraoperative ultrasound confirmed wire stability and accurate positioning in all cases.

Surgical margins

All 104 patients (100%) achieved negative surgical margins on final pathology. Intraoperative frozen section analysis and ultrasound guidance were routinely employed to ensure complete excision.

Device removal

All 104 devices were successfully removed by gentle unscrewing without applying force. No wire displacement occurred during device removal. The elliptical hole design allows smooth wire release without tension, eliminating the risk of wire migration during removal. Intraoperative ultrasound confirmed accurate wire positioning in all cases following device removal.

Complications

No procedure-related complications were observed, including:

- Pneumothorax (0/104)
- Organ injury (0/104)
- Bleeding requiring intervention (0/104)
- Infection (0/104)

Patient tolerance

All patients reported no discomfort related to the screw mechanism. Skin assessments revealed no pressure-related changes, erythema, or induration at the device application site.

Discussion

This study assesses the effectiveness and safety of an innovative screw mechanism designed to prevent wire migration during patient transport for localization of non-palpable lesions and post-NAC clips in breast surgery. The primary objective of the screw mechanism is to enhance patient safety during the critical transport period from radiology to the operating room by effectively ensuring wire stability. Specifically, by preventing wire migration during transport and positioning, accurate localization of lesions is maintained, thereby increasing the success of subsequent surgical procedures.

In this investigation, no complications were noted following the utilization of the screw mechanism. This result underscores the likelihood that the mechanism could be effective in avoiding severe complications such as pneumothorax, organ injuries, and wire migration cited in existing literature [9, 10]. Additionally, it is believed to improve surgical outcomes by lessening the necessity for re-excision owing to positive surgical margins arising from wire migration. Literature indicates that wire migration in conventional methods may extend operation times and necessitate further interventions for patients [4, 11]. Although tested on a limited number of patients in this study, it is quite plausible that the mechanism employed could instill greater confidence in surgeons and radiologists by diminishing the risk of complications.

While other localization techniques such as magnetic localization (Magseed), Savi-scout reflectors, and radio frequency identification (RFID) tags are efficient in locating breast masses, they may encounter accessibility challenges due to higher costs and restricted availability [12–15]. The screw mechanism introduced in our research presents a more affordable and easily applicable alternative while ensuring wire stability. This method, which can be seamlessly implemented with existing instruments, enhances patient safety and streamlines the surgical process. The screw mechanism distinguishes itself as an appropriate option for a broader patient population and demographics owing to its cost-effectiveness and easy accessibility. Hook-wire localization techniques, widely used internationally, rely on tissue anchoring but

can still experience displacement complications [7, 16]. Our external screw mechanism provides additional security during patient transport, complementing the wire's tissue positioning and demonstrating potential as a practical solution in breast surgery.

The screw mechanism devised in this study was designed with an elliptical hole structure to prevent the wire from becoming stuck during exit. If the hole were entirely circular, the wire's stability could be adversely impacted. The slight tilt in the design enhances safety while allowing for a more controlled wire exit. In pulmonary nodule marking systems, specialized stabilization methods such as pure gold cylinders with knurled surfaces are employed to avoid wire migration [17]. Additionally, cement-supported K-wire frameworks have been highlighted as a secure method to deter wire migration and displacement in orthopedics, particularly in distal radius fractures [18]. In neurosurgery, various stabilization mechanisms are applied to secure deep brain stimulation electrodes [19]. This system, relevant to breast surgery, presents an efficient and innovative solution to wire slippage.

While our results are encouraging, direct comparison with standard wire localization was not performed due to the descriptive nature of this study. The absence of a control group limits our ability to definitively claim superiority over existing techniques. Furthermore, we did not collect patient-reported outcome measures or long-term follow-up data, which are essential for comprehensive evaluation of any localization technique. The immediate postoperative outcomes and 4-hour application period provide only a limited assessment window for device safety and efficacy.

This study has several important limitations that must be acknowledged. The descriptive design without a control group precludes direct statistical comparison with standard wire localization techniques and limits our ability to definitively claim superiority over existing techniques. Additionally, the absence of long-term follow-up data and patient-reported outcome measures limits our assessment to immediate perioperative results within a 4-hour application window. Although the complete absence of complications is encouraging, it prevented meaningful statistical analysis of potential risk factors or predictive variables. Furthermore, conducting this study at a single specialized center may limit the generalizability of our findings to institutions with varying levels of expertise and resources. The device also awaits regulatory approval for routine clinical implementation. These limitations underscore the need for multicenter randomized controlled trials with extended follow-up periods to validate our preliminary findings.

In conclusion, this study sought to evaluate the efficacy of the newly developed screw mechanism in preventing

wire migration and promoting patient safety. Its straightforward design, affordability, and practical applicability position this mechanism as a potentially valuable alternative for broader use in clinical environments. The results indicate that this mechanism shows promise as a practical solution for wire stabilization. However, future research should more comprehensively explore the applicability and effectiveness of this mechanism across diverse patient populations through controlled comparative studies.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12893-025-03123-0>.

Supplementary Material 1.

Supplementary Material 2.

Supplementary Material 3.

Supplementary Material 4.

Acknowledgements

None.

Informed Consent

This study was conducted in accordance with the principles of the Declaration of Helsinki. The need for informed consent was waived by the Ethics Committee of Sancaktepe Şehit Prof. Dr. İlhan Varank Training and Research Hospital due to the retrospective nature of the study (Approval Number: 2024/294).

Authors' contributions

Study concepts: IT, AG, OCY, LC. Study design: IT, AG. Data acquisition: IT, AG, KC. Quality control of data and algorithms: IT, AG, OCY, LC. Data analysis and interpretation: IT, AG. Statistical analysis: IT, AG. Manuscript preparation: IT, AG, OCY, LC. Manuscript editing: IT, AG, OCY, LC. Manuscript review: IT, AG, OCY, LC.

Funding

None.

Data availability

The manuscript presents the data. Upon request, the corresponding author can provide the datasets analyzed within this study.

Declarations

Ethics approval and consent to participate

The study was approved by the Ethics Committee of Sancaktepe Şehit Prof. Dr. İlhan Varank Training and Research Hospital (Approval Number: 2024/294). The need for informed consent was waived due to the retrospective nature of the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing financial interests. OCY is listed as one of the inventors on a pending patent application (TR 2023 018924) for the device described in this study. The other patent holders are not authors of this manuscript.

Received: 13 January 2025 / Accepted: 22 July 2025

Published online: 20 August 2025

References

1. Banys-Paluchowski M, Kühn T, Masannat Y, Rubio I, de Boniface J, Ditsch N, et al. Localization techniques for non-palpable breast lesions: current status, knowledge gaps, and rationale for the MELODY study (EUBREAST-4/iBRA-NET, NCT 05559411). *Cancers (Basel)*. 2023. <https://doi.org/10.3390/cancers15041173>.
2. Guirguis MS, Adrada BE, Scoggins ME, Moseley TW, Dryden MJ, Le-Petross HC, et al. The challenging image-guided preoperative breast localization: a modality-based approach. *AJR Am J Roentgenol*. 2022;218(3):423–34.
3. Joret MO, El-Haddawi F. Intraperitoneal migration of a hookwire following wide local excision of a breast lesion presenting as a spontaneous pneumothorax. *BMJ Case Rep*. 2021. <https://doi.org/10.1136/bcr-2021-244086>.
4. Shirazi S, Hajiesmaeili H, Khosla M, Taj S, Sircar T, Vidya R. Comparison of wire and non-wire localisation techniques in breast cancer surgery: a review of the literature with pooled analysis. *Medicina (B Aires)*. 2023;59(7):1297.
5. Dave RV, Barrett E, Morgan J, Chandarana M, Elgammal S, Barnes N, et al. Wire-and magnetic-seed-guided localization of impalpable breast lesions: iBRA-NET localisation study. *Br J Surg*. 2022;109(3):274–82.
6. Subramanian KT, Elnour A, Kurup V. SP6. 3-Comparison of three new wireless non-radiation techniques for localization of non-palpable breast cancer—an updated systematic review and pooled meta-analysis. *Br J Surg*. 2024;111(Supplement 8):znae197.
7. Norman C, Lafaurie G, Uhercik M, Kasem A, Sinha P. Novel wire-free techniques for localization of impalpable breast lesions—a review of current options. *Breast J*. 2021;27(2):141–8.
8. de Albuquerque TL, Júnior JEM, de Queiroz LP, Ricardo ADS, Rocha MVP. Polylactic acid production from biotechnological routes: A review. *Int J Biol Macromol*. 2021;186:933–51.
9. Grassi R, Romano S, Massimo M, Maglione M, Cusati B, Violini M. Unusual migration in abdomen of a wire for surgical localization of breast lesions. *Acta Radiol*. 2004;45(3):254–8.
10. Bachir N, Lemaitre J, Lardinois I. Intrathoracic hooked wire migration managed by minimally invasive thoracoscopic surgery. *Acta Chir Belg*. 2020;120(3):186–9.
11. Da Silva M, Porembka J, Mokdad AA, Seiler S, Huth J, Rivers A, et al. Bracketed radioactive seed localization vs bracketed wire-localization in breast surgery. *Breast J*. 2018;24(2):161–6.
12. Wright CM, Moorin RE, Saunders C, Marinovich ML, Taylor DB, group tRs. Cost-effectiveness of radioguided occult lesion localization using 125I seeds versus hookwire localization before breast-conserving surgery for non-palpable breast cancer. *Br J Surg*. 2021;108(7):843–50.
13. Cullinane CM, Byrne J, Akmenkalne L, O'Leary DP, Connors AM, Corrigan MA, et al. The localizer radiofrequency identification system: an effective new technology for localizing non-palpable breast lesions for surgery. *Surg Innov*. 2020;28(4):473–8.
14. Ross F, Elgammal S, Reid J, Henderson S, Kelly J, Flinn R, et al. Magseed localization of non-palpable breast lesions: experience from a single centre. *Clin Radiol*. 2022;77(4):291–8.
15. Subramanian KT, Elnour A, Kurup V. Comparison of three new wireless non-radiation techniques for localisation of non-palpable breast cancer—an updated systematic review and pooled meta-analysis. *Clinical Surgical Oncology*. 2024. <https://doi.org/10.1016/j.cson.2024.100051>.
16. Shirazi S, Hajiesmaeili H, Khosla M, Taj S, Sircar T, Vidya R. Comparison of wire and Non-Wire localisation techniques in breast cancer surgery: A review of the literature with pooled analysis. *Med (Kaunas)*. 2023 Jul 13;59(7):1297.
17. Keating J, Singhal S, editors. Novel methods of intraoperative localization and margin assessment of pulmonary nodules. *Seminars in thoracic and cardiovascular surgery*. Elsevier; 2016.
18. Meng H, Xu B, Xu Y, Niu H, Liu N, Sun D. Treatment of distal radius fractures using a cemented K-wire frame. *BMC Musculoskelet Disord*. 2022;23(1):591.
19. Dorfer C, Stefanits H, Pataria E, Wolfsberger S, Feucht M, Baumgartner C, et al. Frameless stereotactic drilling for placement of depth electrodes in refractory epilepsy: operative technique and initial experience. *Oper Neurosurg*. 2014;10(4):582–91.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.