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Review Article

Integrating Artificial Intelligence for Improved Management of Frozen Shoulder and Complications in Breast Cancer Surgery: A Perspective from Thailand

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Abstract

Breast cancer is a leading cause of mortality among women worldwide, necessitating surgical interventions like lumpectomy, mastectomy, or modified radical mastectomy. However, these procedures often lead to postoperative complications, such as frozen shoulder, significantly impacting patients's quality of life. This review focuses on the challenges associated with frozen shoulder and other complications following breast cancer surgery. It proposes the integration of Artificial Intelligence (AI) in assessment and intervention as a cost- effective solution. Frozen shoulder, also known as adhesive capsulitis, affects around 22.2% of breast cancer patients, particularly those undergoing axillary approaches. It is frequently accompanied by Axillary Web Syndrome (AWS) and Post-Mastectomy Pain Syndrome (PMPS), resulting in pain, limited range of motion, and compromised functional abilities. Conservative treatments, including exercises and rehabilitation programs, have shown positive outcomes in managing these symptoms. Previous studies have demonstrated the effectiveness of exercises, joint mobilization techniques, and home-based exercise programs in improving muscle strength, range of motion, and functional ability in breast cancer survivors. Abnormal neuromuscular control and kinematic distortions in shoulder and spinal movements have also been identified, highlighting the significance of neuromuscular training for shoulder joint complex recovery. The integration of AI in the assessment and intervention of frozen shoulder can offer cost-effective solutions and reduce waiting times at healthcare centers in Thailand. AI technologies can enable precise evaluations and personalized treatment plans, optimizing patient outcomes and resource utilization. In conclusion, physical therapy plays a crucial role in managing frozen shoulder and other complications following breast cancer surgery. Evidence-based practices, including comprehensive patient education, tailored exercise programs, manual therapy techniques, and pain management strategies, are essential for effective treatment. Integrating AI in assessment and intervention can further enhance outcomes and alleviate the burden on healthcare resources.

Keywords: Frozen shoulder; Adhesive capsulitis; Breast surgery; Breast cancer; Physical therapy; Artificial intelligence

Introduction

Breast cancer persists as the predominant cause of mortality in the female population on a global scale. Surgical interventions, such as lumpectomy, mastectomy, and modified radical mastectomy, are frequently employed as standard treatment modalities for this disease. Nevertheless, it is imperative to acknowledge that these procedures carry the possibility of giving rise to postoperative complications, among which is the potential development of frozen shoulder, medically termed adhesive capsulitis [1,2]. Adhesive capsulitis, commonly known as frozen shoulder, represents a prevalent issue that typically emerges during the 13-18 month period following surgical intervention . Frozen shoulder exhibits a substantial prevalence rate of ap-

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proximately 22.2% [3]. Furthermore, it is important to note that breast surgery involving axillary approaches, such as Sentinel Lymph Node Biopsy (SLNB) or Axillary Lymph Node Dissection (ALND), contributes to an increased incidence of frozen shoulder [2,4]. In addition, it is worth noting that cases involving breast surgery with axillary approaches can lead to the occurrence of postoperative Axillary Web Syndrome (AWS) [5,6] and Post-Mastectomy Pain Syndrome (PMPS) [7]. These conditions manifest as axillary pain, shoulder pain, limited Range of Motion (ROM) in the affected shoulder, and a compromised quality of life [6,8].

Conservative treatment options, encompassing exercises and rehabilitation programs, have demonstrated efficacy in ameliorating symptoms and enhancing the performance of daily activities. In contrast to instrumental physical therapy and anti-inflammatory drug therapy, these conservative approaches offer favorable outcomes [7]. In a previous study, eccentric and concentric contraction exercises were found to improve muscle strength and function in fifteen out of thirty female patients diagnosed with frozen shoulder [9]. Engagement in postoperative rehabilitation exercises has been shown to facilitate the improvement of patients' functional ability [10]. A postoperative extramural domicile-based exercise program has demonstrated effectiveness in promoting the recovery of flexion, abduction, and extension movements in the ipsilateral shoulder. This positive outcome was observed when the program was consistently followed for a minimum duration of 105 days following mastectomy and 75 days following quadrantectomy [11]. Furthermore, the application of physical therapy incorporating joint mobilization techniques, specifically anteroposterior gliding, has been shown to enhance shoulder Range of Motion (ROM) [12]. The data presented signifies that long-term follow-up, coupled with physical therapy incorporating targeted exercises and conservative treatment modalities, can significantly contribute to the further improvement of frozen shoulder and shoulder complex dysfunction subsequent to breast cancer surgery.

The aim of this review is to highlight the significant issues identified in our research regarding physical therapy following breast cancer surgery in Thailand. Additionally, we propose introducing an Artificial Intelligence (AI) perspective on the assessment and intervention of frozen shoulder as a cost-effective solution to mitigate the high expenses and reduce waiting times at healthcare centers in Thailand.

Breast Cancer and the Associated Complications Following Breast Surgery

Breast cancer, accounting for 30% of female cancers (281,550 cases), emerged as the most prevalent cancer diagnosed in women in 2021 [13]. The estimated number of cancer- related deaths among Americans in 2021 stood at 608,570 [14]. The incidence rate of cancer is projected to increase by 0.5% annually [14]. Following a breast cancer diagnosis, the majority of women undergo some form of breast surgery as part of their treatment, aiming to achieve complete tumor removal [14]. The decision to recommend a specific surgical procedure is based on the patient's cancer characteristics and medical history. Survivors of breast cancer treatment often encounter complications, including frozen shoulder [2,15-18], chronic pain [1,18], and lymphedema [5,19,20]. These multiple issues may arise simultaneously, posing challenges in identifying precise causes and implementing appropriate management strategies. In a cross-sectional observational study involving 135 Asian women who underwent breast cancer surgery, 22.2% developed frozen shoulder [5]. Other cross- sectional studies reported incidences of frozen shoulder at 10.3% among 271 women [2] and 3.8% among 785 patients [1]. Frozen shoulder incidence following mastectomy was found to be higher in the 50-59 age group [2,21]. Additionally, the risk of frozen shoulder is further increased with breast reconstruction procedures [1,2].

Frozen shoulder is a distressing condition that inflicts pain and significantly impairs the quality of life for breast cancer patients. The etiologies of frozen shoulder, as evidenced by databases, are not yet fully understood. Another form of adhesive capsulitis, characterized by debilitation of the shoulder joint, particularly the Glenohumeral joint (GH), occurs as a result of surgery [1]. The majority of frozen shoulder cases can be attributed, at least in part, to the contracture of the GH joint capsule, which arises from inflammatory processes, fibrosis, and excessive scar tissue adhesion [22]. Interestingly, shoulder Range of Motion (ROM) on the unaffected side also experiences a decrease [22]. Clinically, patients commonly present with shoulder pain and limited ROM, typically manifesting as reduced abduction and internal rotation during both active and passive movements [23,24]. Frozen shoulder is often accompanied by pain, and previous reports indicate that levels of pain and dysfunction correlate with altered kinematics (25). Distinguishing between frozen shoulder and shoulder impingement syndrome can be challenging. Persistent pain following breast cancer treatment is frequently referred to as post-mastectomy pain syndrome (PMPS), which tends to worsen with shoulder movement. Repetitive movements can perpetuate the inflammatory process and the adhesion of scar tissue, further restricting shoulder mobility [22,26]. However, additional clinical studies have demonstrated the involvement of other joints following breast surgery, including the Sternoclavicular (SC) joint, Acromioclavicular (AC) joint, and Scapulothoracic (ST) joint. Dysfunction in these joints can contribute to shoulder complex dysfunction since normal ROM and pain-free motion of the arm and shoulder depend on their mobility [8].

Shoulder complex dysfunction and kinesiologic impairment following breast cancer surgery Inflammation, pain, and excessive scar tissue adhesion are well-established factors in frozen shoulder [26]. It is important to understand the impaired movement patterns of the shoulder complex that occur after developing frozen shoulder. The scapulohumeral rhythm, which refers to the movement of the scapula and the humerus, has been extensively discussed due to its disproportionate influence on shoulder movements. It is recognized that limitations in shoulder movements are not solely caused by the movement of the Glenohumeral (GH) joint but also involve the movement of the Scapulothoracic (ST) joint [22,27,28]. Despite the convincing nature of this principle, the evidence regarding abnormal movement patterns remains inconclusive.

A cross-sectional descriptive study involving 90 female participants demonstrated that breast cancer treatment resulted in alterations in the neuromuscular activity of the shoulder. These alterations were associated with the presence or absence of persistent pain and were more pronounced when persistent pain was present [29].

Data obtained from Surface Electromyography (sEMG) for five different shoulder muscles during three specific movements (abduction, forward flexion, and external rotation) reveal significant findings as follows: 1) In all movements, the upper trapezius muscle exhibited early activation, while the muscles related to the rotator cuff, anterior deltoid, middle deltoid, and posterior deltoid muscles showed delayed activation. 2) Shoulder abduction and forward flexion resulted in delayed activation of the lower trapezius muscle, along with delayed activation of the serratus anterior muscle. 3) The shoulder's external rotation movement also exhibited delayed activation of the lower trapezius muscle and the serratus anterior muscle. 4) Increased amplitude of upper trapezius muscle activity was observed in all movements. 5) Decreased amplitude of serratus anterior and lower trapezius muscle activity was present in all movements. 6) There was increased amplitude of anterior deltoid and middle deltoid muscle activity in all movements, but decreased amplitude of posterior deltoid muscle activity. 7) The impairment of shoulder neuromuscular activity was more pronounced in patients experiencing shoulder pain. The alterations in shoulder neuromuscular activity identified in this study are closely linked to changes in the complex kinematics of the shoulder joint. Insufficient function of the serratus anterior and middle trapezius muscles contributes to excessive scapular internal rotation, leading to conditions such as winged scapula [18] or scapula alata [30]. Similarly, a decrease in serratus anterior and lower trapezius muscle activity, coupled with an increase in upper trapezius muscle activity, can result in excessive scapular anterior tilt, scapular internal rotation, and inadequate scapular upward rotation [31,32]. Previous research has also indicated that excessive scapular anterior tilt is commonly observed in shoulder pain disorders [33], likely influenced by an impairment of the optimal length of the pectoralis minor muscle [34]. Clinical practices have further demonstrated the importance of strengthening the pectoralis minor antagonistic muscle, the lower trapezius [35].

Anatomical damage and musculoskeletal tissue damage resulting from breast cancer surgery can trigger neuroplastic, biochemical, and neuromuscular changes, which collectively contribute to clinical pain and shoulder dysfunction [36,37]. Nociceptive stimuli originating from myofascial tissue, neural tissue, and vascular tissue have the potential to activate somatosensory neurons in the somatosensory cortex, leading to pain-induced inhibition of the primary motor cortex [38,39]. These alterations in primary motor cortex neuronal activity affect the motor control of the shoulder [40]. Current evidence indicates that cognition-targeted therapeutic exercises utilizing neuromuscular training can enhance the neuromuscular coordination of shoulder muscles [39,41-45]. Therefore, incorporating neuromuscular training for the shoulder joint complex can improve shoulder neuromuscular activity in breast cancer survivors post-surgery.

In a prospective longitudinal study involving 30 participants before and after breast cancer treatment, results showed that shoulder dysfunction was associated with a decrease in supraspinatus tendon thickness from 4.74±1.04 mm at 7–10 days after surgery to 4.52±0.99 mm at 6 months after surgery [46]. This reduction in tendon thickness may be attributed to a creep-related phenomenon [16] and fluid displacement from the tendon [47-49]. Notably, a reduction in shoulder flexion and abduction was observed at 7–10 days post-surgery, while a progressive recovery of shoulder flexion, extension, and abduction was demonstrated in subsequent follow-up assessments [50]. Range of Motion (ROM) appeared to return to normal in the subsequent follow-up evaluations [16]. Similarly, submaximal isometric contractions of shoulder movements were significantly decreased at 7-10 days post-surgery, but a progressive recovery was observed in all movements during subsequent follow-up assessments [16]. Additionally, shoulder pain, shoulder disability, and disability scale scores significantly increased at 7–10 days post-surgery but progressively recovered over time, returning to normal levels at the 6-month follow-up [16]. However, these findings are inconsistent with those of Min et al., who reported that ROM on the affected side had returned to pre-surgery levels just 24 days after the operation [16].

Current neuroscience studies suggest that abnormal neuromuscular control resulting from repetitive triggering of nociceptive input, primary motor cortex inhibition, activation of abnormal motor strategies, and overloading of peripheral structures could contribute to shoulder joint dysfunction, ultimately impacting quality of life [23,38,51]. Descriptively, patterns of ROM recovery may vary according to the surgical type. Nevertheless, the sample sizes in these studies were relatively small [16,39] and factors such as medication usage, engagement in sports activities, and other conservative treatments that may have influenced the results were not discussed. Furthermore, the mechanistic insights into self-recovery outcomes in these studies were not presented [16,23].

In an observational study involving fifty-three women who underwent unilateral mastectomy, complex kinematic distortions in shoulder and spinal movements were identified [23]. These distortions led to alterations in the relationship between movement patterns of the Scapulothoracic (ST) joints and Glenohumeral (GH) joints, resulting in a significant increase in scapular upward rotation and scapular excursion [52].

Almost all breast cancer survivors experience frequent and significant shoulder morbidities immediately after undergoing breast cancer surgery. Data suggests that the most common problem following breast cancer treatment is pain, which can be classified as somatic and neuropathic in nature [52]. Notably, neuropathic pain often arises from damage to various nerves, including the intercostobrachial nerve, thoracodorsal nerve, long thoracic nerve, anterior and lateral cutaneous branches of the intercostal nerve T3-T6, the pectoralis medial nerve, and the pectoralis lateral nerve [53-55]. Injury to multiple nerve branches affects both sensory and motor function, leading to the loss of motor control in muscles such as the pectoralis, serratus anterior, and latissimus dorsi, due to damage to the pectoral nerve, long thoracic nerve, and thoracodorsal nerve, respectively [53-56]. Additionally, regional musculoskeletal dysfunction contributes to dysfunction of the shoulder complex.

The term "shoulder complex dysfunction" or "shoulder girdle impairment" is used to describe abnormalities in shoulder joint movements [56]. Exercise programs aimed at improving Range of Motion (ROM) should not only focus on ROM enhancement but also on postural correction, pain reduction, and improved ease in performing Activities of Daily Living (ADL). It is also essential to consider the long-term effects of exercise programs.

Evidence Based Management in Frozen Shoulder Following Breast Cancer Surgery

The management of frozen shoulder following breast cancer surgery should be based on evidence-based practices to ensure effective and appropriate treatment. Several strategies have been identified in the literature for managing frozen shoulder in breast cancer survivors. Providing patients with comprehensive education about the condition, its course, and available treatment options is crucial. This empowers patients to actively participate in their care and make informed decisions. Comprehensive patient education is crucial in the management of frozen shoulder following breast cancer surgery. By providing patients with information about the condition, its progression, and available treatment options, they can actively participate in their care and make informed decisions. Physical therapy plays a vital role in improving shoulder mobility and function through a combination of stretching exercises, range of motion exercises, and strengthening exercises, tailored to the specific needs of breast cancer survivors, considering their surgical history and related impairments. Manual therapy techniques, such as joint mobilization and soft tissue mobilization, performed by trained physical therapists or healthcare professionals, can further enhance shoulder mobility and alleviate pain. Pain management strategies, including NSAIDs, corticosteroid injections, or other medications, should be carefully considered, taking into account contraindications and potential side effects. Adopting a collaborative approach involving orthopedic specialists, oncologists, physical therapists, and pain management specialists optimizes patient outcomes by tailoring treatment plans to individual needs. The use of evidence-based interventions, guided by guidelines and research studies, ensures effective management. Regular long-term follow-up assessments are essential for monitoring progress, adjusting treatment plans, and addressing persistent impairments or pain. Maintenance exercises and strategies can be implemented to prevent recurrence and complications. Overall, implementing evidence-based management strategies improves the quality of life for breast cancer survivors with frozen shoulder following surgery.

In 2020, the multicenter, randomized UK Frozen Shoulder Trial (UK-FROST) conducted a significant trial involving primary frozen shoulder patients. The trial demonstrated substantial improvements in both pain and function through various treatment modalities, including manipulation under anesthesia, arthroscopic capsular release, and early structured physiotherapy [57,58]. These findings have important implications for clinicians in advising patients about treatment options. However, it should be noted that in some cases, patients undergoing early structured physiotherapy may require additional treatment to achieve optimal outcomes.

The Perspective of AI and Telemedicine in Physical Therapy Assessment and Management in Thailand

AI and telemedicine have the potential to revolutionize physical therapy assessment and management in Thailand, bringing numerous benefits to the field. One significant advantage of AI is its ability to analyze large amounts of patient data and provide accurate assessments of movement patterns, strength, and functional abilities. This assists physical therapists in making informed decisions and developing personalized treatment plans tailored to each patient's specific needs. By leveraging AI technology, physical therapy practices can enhance their diagnostic capabilities and improve treatment outcomes.

On the other hand, telemedicine offers a transformative approach to healthcare delivery. It enables remote consultations, breaking down geographical barriers and providing access to expert physical therapy services for patients in remote areas or with limited mobility. This not only increases accessibility to care but also promotes continuity of care by facilitating regular monitoring and follow-up. Through telemedicine, patients can receive ongoing guidance and support from physical therapists without the need for frequent in-person visits. This is particularly beneficial for individuals who face challenges in traveling or have limited access to specialized physical therapy services.

However, the integration of AI and telemedicine in physical therapy assessment and management in Thailand comes with its own set of challenges and limitations. One primary concern is the need for infrastructure development. Robust internet connectivity is essential for seamless telemedicine consultations and efficient data transmission between healthcare providers and patients. Additionally, secure platforms for data storage and transmission are crucial to protect patient privacy and ensure data security. Investing in infrastructure development is essential to establish a solid foundation for the widespread adoption of AI and telemedicine technologies in physical therapy.

Another challenge lies in the training and education of physical therapists to effectively utilize AI tools and telemedicine platforms. To optimize the implementation of these technologies, physical therapy curricula should incorporate AI and telemedicine education. Providing training opportunities for physical therapists to familiarize themselves with AI algorithms, telemedicine platforms, and best practices for remote consultations will enhance their skills and knowledge in utilizing these technologies effectively. Continuous professional development programs can further support physical therapists in staying updated with the latest advancements in AI and telemedicine.

The integration of AI and telemedicine in physical therapy assessment and management holds immense potential for transforming healthcare services in Thailand. Overcoming challenges such as infrastructure development and ensuring adequate training for physical therapists is crucial for successful implementation. By embracing AI and telemedicine, Thailand can advance its physical therapy practices, improving accessibility, quality of care, and patient outcomes. It is an exciting opportunity to leverage technology to enhance the delivery of physical therapy services and address the healthcare needs of the population more effectively.

Discussion

Breast cancer surgery is a common treatment modality for breast cancer, but it can lead to complications such as frozen shoulder, AWS, and PMPS. These conditions significantly impact the quality of life for patients and require appropriate management strategies. Conservative treatment options, including exercises and rehabilitation programs, have shown favorable outcomes in improving symptoms and functional ability. Physical therapy incorporating targeted exercises and joint mobilization techniques can enhance shoulder ROM and contribute to the recovery of frozen shoulder and shoulder complex dysfunction. The prevalence of frozen shoulder following breast surgery is substantial, with rates ranging from 3.8% to 22.2%. Age and breast reconstruction procedures further increase the risk of frozen shoulder. Frozen shoulder is characterized by pain, limited ROM, and altered shoulder kinematics. It is often accompanied by shoulder impingement syndrome and PMPS. Anatomical and musculoskeletal tissue damage resulting from breast surgery trigger neuroplastic, biochemical, and neuromuscular changes, contributing to clinical pain and shoulder dysfunction.

Studies have shown altered neuromuscular activity and impaired movement patterns of the shoulder complex in breast cancer survivors post-surgery. These alterations are associated with persistent pain and contribute to excessive scapular anterior tilt, scapular internal rotation, and inadequate scapular upward rotation. Strengthening the antagonistic muscles, such as the lower trapezius, and incorporating neuromuscular training can improve shoulder neuromuscular activity. The recovery of shoulder function and ROM after breast cancer surgery varies depending on the surgical type, but overall, a progressive recovery is observed over time. However, the evidence regarding self-recovery outcomes is limited, and factors such as medication usage and engagement in sports activities are not well-discussed. Additionally, complex kinematic distortions in shoulder and spinal movements have been observed following unilateral mastectomy, leading to alterations in the relationship between the scapulothoracic and glenohumeral joints.

The management of frozen shoulder following breast cancer surgery should be based on evidence-based practices. Comprehensive patient education is crucial to empower patients to actively participate in their care and make informed decisions. Physical therapy, including stretching exercises, range of motion exercises, and strengthening exercises, tailored to the specific needs of breast cancer survivors, plays a vital role in improving shoulder mobility and function. Manual therapy techniques, such as joint mobilization and soft tissue mobilization, can further enhance shoulder mobility and alleviate pain. Pain management strategies should be carefully considered, taking into account individual patient factors and preferences. The current physical therapy assessment and management practices in Thailand are still lacking in advancements that utilize AI or telemedicine systems. While initiating a large-scale project for implementing these ideas may involve significant costs for systemic innovation, we firmly believe that the implementation of AI or telemedicine systems can provide a long-term solution to address and mitigate this issue.

Conclusion

Physical therapy and conservative treatment options are effective in managing frozen shoulder and shoulder complex dysfunction following breast cancer surgery. The incorporation of targeted exercises, joint mobilization techniques, and neuromuscular training can improve shoulder neuromuscular activity and enhance functional outcomes. Comprehensive patient education and evidence-based management strategies are essential to optimize the care and rehabilitation of breast cancer survivors with frozen shoulder. Introducing an AI perspective on the assessment and intervention of frozen shoulder may also provide a cost-effective solution to mitigate high expenses and reduce waiting times at healthcare centers. Further research and larger studies are needed to better understand the mechanisms underlying shoulder dysfunction and to optimize treatment approaches for breast cancer survivors.

Author Statements

Conflicts of Interest

We declare no competing interests.

Authors Contribution

The manuscript was planned, reviewed, and drafted by TP&PT. TP&PT also edited and revised the manuscript. The final version of the manuscript was approved by TP&PT.

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