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Surgical Site Soft Tissue Thickness as a Predictor of Complications Following Arthroplasty

Surgical Site Soft Tissue Thickness

Abstract

Appreciation of soft-tissue thickness (STT) at surgical sites is an increasingly recognized aspect of arthroplasty procedures as it may potentially impacting postoperative outcomes. Recent research has focused on the predictive value of preoperative STT measurements for complications following various forms of arthroplasty, particularly infections, across procedures such as total knee, hip, shoulder, and ankle replacements. Several studies have indicated that increased STT is associated with a higher risk of complications, including infection and wound healing issues. The assessment of STT before surgery could play a crucial role in identifying patients at a higher risk of complications and may be instrumental in guiding preoperative planning to optimize outcomes in arthroplasty procedures. Standardized measurement techniques and further research are essential to enhance the reliability and clinical utility of STT assessment for arthroplasty surgery.

Key Words: Soft-Tissue Thickness; Arthroplasty; Surgical Complications; Total Knee Arthroplasty; Total Hip Arthroplasty; Total Shoulder Arthroplasty; Total Ankle Arthroplasty; Preoperative Assessment; Wound Healing; Infection Risk

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Core Tip: This review examines the relationship between preoperative soft-tissue thickness and surgical complications in total knee arthroplasty (TKA), total hip arthroplasty (THA), reverse shoulder arthroplasty (RSA), and total ankle arthroplasty (TAA). By synthesizing findings from multiple studies, we highlight the significant correlation between increased soft-tissue thickness and higher complication rates. Our review underscores the importance of thorough preoperative assessment of soft-tissue thickness to enhance surgical planning and patient outcomes in various arthroplasty procedures.

INTRODUCTION

Total Joint Arthroplasty (TJA), which encompasses total hip arthroplasty (THA) and total knee arthroplasty (TKA) in addition to other forms of joint arthroplasty, is on the global rise due to its success in treating osteoarthritis (OA) and other debilitating joint conditions[1, 2]. Along with an increase in OA in an aging population, comes an increase in arthroplasty procedures worldwide to restore mobility and help alleviate pain[3,4]. However, TJA, along with other surgical procedures, is not without risks and complications, which include surgical site and periprosthetic infection[5, 6, 7, 8, 9]. Infection can prolong hospital stay, increase costs, and even induce further surgeries or permanent disability[10]. Other complication includes anesthetic-related issues, blood transfusion-related problems, and venous thromboembolism (VTE)[11]. These complications can be directly associated with increased morbidity and mortality. Therefore, understanding the risk factors for these complications must be understood to minimize risks and promote favorable outcomes.

Traditionally, body mass index (BMI) has been used to stratify patient risk before a TJA is performed due to its association with obesity, which has been a known risk factor for poorer surgical outcomes across a number of TJA procedure subtypes[12]. However, BMI can be a flawed measurement due to its poor ability to distinguish between muscle and fat within a body mass composition, and therefore lacks the ability to gauge for the presence of increased fatty soft tissue overlying the joint of interest[13,14,15,16]. Moreover, an individual with higher muscle compared to one with higher fat may have a lower risk for complications despite having a similar BMI. Alternative quantification methods, such as percent body fat and bioelectrical impedance analysis, correlate strongly with perioperative risks following TJA[17,18,19]. However, these measures require special testing that may not be easily accessible.

Soft-tissue thickness (STT) around the surgical site has shown relevance in predicting TJA outcomes and complications[20]. Increased STT can potentially complicate the arthroplasty surgery by requiring more dissection and retraction, which can lead to malalignment, component instability, longer operative duration, and post-operative infection and pain[21,22,23,24]. Advanced radiographic methods, such as magnetic resonance imaging (MRI) and computed tomography (CT) scans, can be used to further characterize the extent of the surgical site. Developing these radiographic measurements may offer precise measurements of STT and proved a representation of the local tissue geography. These measurements can provide anticipatory and management information regarding the complexity and complications of tissue retraction and alignment during the procedure. One study has indicated that increased STT, measured by preoperative MRI, is associated with a higher risk for wound complications after THA[25]. While STT shows promise as a marker for increased complications across various arthroplasty procedures, the use of this metric is not widespread and has not been reported across outcomes studies.

Thus, this review aims to examine and understand the effects of the extensivity of local periarticular STT on surgical outcomes following several varieties of TJA. By comparing the predictive value between STT and BMI, the review seeks to identify reliable yet accurate risk stratification methods. Understanding the application of STT could lead to improvements in surgical anticipation and management, therefore improving patient outcomes in TJA.

Knee Arthroplasty

The most prevalent TJA procedure is TKA, and the incidence of the procedure continues to increase. TKA is primarily performed in patients who have OA, rheumatoid arthritis (RA), and post-traumatic arthritis. Approximately seven studies investigated STT as a possible determinant of complication within TKA (Table 1). Of these seven studies, four found STT to be a significant determinant, while three of the studies did not find an association. The articles are summarized in Table 1.

Wagner *et al*. conducted a retrospective review in which the Patella-Femur Thickness Ratio (PFTR) was calculated to measure STT around the knee as a predictive measure to anticipate postoperative complications, specifically surgical site infection (SSI), after TKA[23]. This analysis of 528 patients indicated that those with a PFTR > 1 had a higher infection rate (5%) compared to patients with a PFTR < 1, indicating that PFTR may be a more reliable indicator of SSI risk than BMI, particularly in obese patients. The study included a small sample size of infections (n = 12), reducing the power of the statistical analysis. Moreover, the study was specific to the center of the patella, reducing a capacity to understand the implication of fatty deposition in other areas of the knee.

Similarly, Yu *et al*. developed tibial and femoral Preoperative Anterior Soft-Tissue Index (PASTI) ratios that deviated from lateral knee radiographs to predict postoperative complications[25]. The study indicated that among 374 patients, those with high PAST (> 3.0) had significantly higher rates of minor complications for both tibial (P < 0.001) and femoral (P < 0.013) measurements, indicating a better predictor of complications of BMI. BMI indicated no significant correlation. The study was limited in its retrospective nature and dependency on accurate X-ray techniques for PASTI measurements.

Watts *et al*. used lateral knee radiographs to measure prepatellar thickness (PPT) and pretubercular thickness (PTT) to examine the relationship with early preoperative risk due to wound complication or infection after TKA in morbidly obese patients[24]. The study found that PPT and PTT are more predictive than BMI, indicating those with PPT ≥ 15 mm and PTT ≥ 25 mm had higher risks of reoperation (relative risks of 2.0 and 1.6, respectively. The study stated that BMI did not correspond with an increased preoperative risk. The study was limited in its retrospective design, possibly overlooking other surgical factors such as techniques and postoperative care.

Vehedi *et al*. investigated medial and anterior STT from AP and lateral radiographs to assess the association between STT and the risk of periprosthetic joint infection (PJI) following TKA[22]. The study indicated that patients with a higher prepatellar fat thickness ratio (PFTR) had an increased risk of infections. Those with a PFTR ≥ 1 had an infection rate of 5%, while those with PFTR < 1 had infection rates of 1.5% ($P < 0.05$). The study was limited in its retrospective design and relatively small number of infection cases ($n = 12$), limiting the generalizability of the study.

Gupta and Kejriwal assessed anterior subcutaneous fat thickness and superficial wound complications in nonmorbidly obese patients who underwent TKA[26]. Within the 494 patients, those with a pretubercular thickness (PTT) ≥ 12 mm had a significantly lower risk to develop superficial complications within 90 days of the operation (relative risk 0.54, P = .028. The results also indicated that prepateller thickness (PPT) showed no significant association. The study was limited in its retrospective design and small sample size. Additionally, there were no comparison groups for patients with BMI ≥ 40. The inter-rater and intra-rater reliability was not discussed.

Secrist *et al*. investigated whether BMI or lower extremity growth ratio (LEG) is a better predictive measure for complications in TKA[27]. Within 453 patients, those with LEG ratios above or below 5 indicated no significant difference in postoperative complication rates. However, BMI > 35 was more predictive of complications (P = 0.0637). Moreover, the sensitivity and specificity of the LEG ratio as a predictive measure were poor. The study was limited in its retrospective design and unvalidated LEG ratio method. Intraoperative variables and comorbidities were not considered as well.

Shearer *et al*. investigated the predictive value of BMI and local knee adiposity measures for PJI and surgical duration after TKA[28]. The results indicated that those with a BMI > 35 were significantly associated with a higher risk for PJI (odds ratio 2.9, 95%CI 1.4-6.1). Conversely, knee adipose index (KAI) and prepatellar fat thickness did not correlate significantly with PJI. BMI and local adiposity measures correlated with higher surgical duration. The study was limited in its retrospective design and variability in X-ray techniques. Additionally, the infection rates were only captured within one year postoperatively, potentially not fully capturing the extensivity of possible infections.

Taken together, a growing number of studies have indicated that increased STT around the knee may correspond to higher complication risk and rates following TKA. Specific complications include SSI, PJI, and wound complications such as hematomas and wound dehiscence. Moreover, STT can lead to greater dead space, affecting wound healing in knee arthroplasty, resulting in prolonged operative times and more extensive soft tissue injury. Therefore, accurate preoperative assessment is imperative.

Hip Arthroplasty

THA is most commonly indicated in patients with primary OA of the hip, osteonecrosis of the femoral head, and femoral neck fractures[29]. Pre-operative assessment and planning in THA patients is critical, just as in any arthroplasty or surgical procedure. Radiographs with quantified magnification of the hip are obtained to initiate pre-operative planning with assessing anatomical landmarks, establishing acetabular cup and femoral stem size, and anticipating intra- and post-operative challenges[30].

Obesity, defined as a BMI ≥ 30 kg/m^2, is a reducible risk factor that may be associated with some intra- and post-operative challenges. High BMI may pose an increased risk of superficial and deep infections, hip dislocations, re-operations, revisions, and readmissions[31,32] in THA. In one study regarding wound drainage in THA, obesity was shown to prolong wound healing, with morbidly obese patients having increased time to dry wounds. Furthermore, prolonged wound drainage was shown to be a significant predictor of wound infection[33]. Studies have shown that increased wound drainage time is associated with post-operative THA wound infection – both deep wound infections and superficial soft-tissue infection[34,35].

In addition, STT has been posed as another risk factor for complications in THA. There were eight articles examining the effect of STT on THA complications (Table 2). Measurement methodology of STT differed amongst studies, with two studies reporting thickness ratios, four studies reporting fat depth from greater trochanter (GT) to skin, and two studies using anterior superior iliac spine (ASIS) and pubic symphysis (PS) as measurement landmarks (Table 2). A variety of approaches exist amongst studies, with anterior, anterolateral, and posterior being the most common. Association between STT and THA complications varied between studies, with some concluding that increased STT increases risk of wound and post-operative complications[36,37,38] and other studies noting no such association[39]. In one study looking at associated characteristics in patients with increased STT, it was found that STT was greater in lateral hip incision approaches as compared to the anterior approach[40]. In addition, a greater BMI was associated with a greater STT with predominance of lateral fat greater in women[40]. However, as noted by Mayne *et al*, BMI is a non-specific indicator of obesity and does not take into account anatomy such as fat distribution. Thus, STT and BMI are not necessarily interchangeable and STT may offer unique predictive value that BMI does not[41].

Some studies analyzed the effect of STT on post-operative acetabular cup positioning. Cup positioning in THA is critical, as malpositioning may lead to loosening of hardware, impingement, and increased rate of post-operative hardware dislocation. Increased STT is believed to obscure anatomical landmarks and increase rates of acetabular cup malpositioning[42]. Hohmann *et al* reported no significant relationship between STT and acetabular cup placement[29], while Suzuki *et al* reported that PS-thickness and ASIS-thickness were associated with cup implantation errors[43].

Limitations to the current literature on STT and complications of THA include the small sample size of patients that develop post-operative complications or re-operation. Another limitation is inherent in the imaging data available – positioning of patients, calibration markers, and magnification can all skew measurements[29,39,40]. Rey Fernández *et al*. has indicated that increased STT, measured by preoperative MRI, is associated with a higher risk for wound complications after THA[36].

Shoulder Arthroplasty

OA, RA, complex fractures of the proximal humerus, osteonecrosis of the humeral head, irreparable tears of the rotator cuff with or without arthropathy, and revisions of failed prosthesis are the most commonly indicated reasons to perform shoulder arthroplasty.[44] Shoulder arthroplasty can serve as a successful treatment option for this variety of pathologies once nonsurgical options have been exhausted.[44, 45, 46] Between 2011 and 2017, the number of primary shoulder arthroplasties increased by 103.7%, and reverse shoulder arthroplasties (RSA) increased by 191.3%. A linear projection model and Poisson model have predicted a 67.2% and 235.2% increase in shoulder arthroplasties, respectively, by 2025.[46]

A meta-analysis from Bohsali *et al.*, examined articles published between 2006 and 2015 pertaining to total shoulder arthroplasty (TSA) complications and RSA complications. The overall complication rate for both procedures was 11%. For TSA, common complications from highest to lowest incidence were component loosening, glenoid wear, instability, rotator cuff tear, periprosthetic fracture, neural injury, infection, hematoma, deltoid injury, and VTE. For RSA, common complications from highest to lowest incidence were instability, periprosthetic fracture, infection, component loosening, neural injury, acromial and/or scapular spine fracture, hematoma, deltoid injury, rotator cuff tear, and VTE.[47]

To date, there is no literature evaluating the role of radiographic STT in predicting TSA complications. In RSA, increased radiographic STT has been identified as a significant predictor of operative and post-operative complications. In a retrospective chart review of patients who underwent RSA, a greater shoulder STT from measurements of the radius from the humeral head center to the skin, deltoid radius-to-humeral head radius ratio, deltoid size, and subcutaneous tissue size were demonstrated to be a strong predictor of operative time, length of stay, and postoperative infection rate (Table 3) .[48] Specifically, the distance from the humeral head center to the skin was shown to have the highest predictive power for these outcomes.[48] Thus, indicating that greater STT poses a substantial challenge during RSA, leading to prolonged surgeries and increased postoperative complications.

STT can be obtained relatively easily from the preoperative radiograph, thus allowing for an estimation of adipose tissue distribution at the surgical site. Furthermore, prior operative shoulder surgical status and patient smoking status should be of particular interest. Orthopaedic surgeons may use this assessment to plan for potential postoperative complications in patients with greater STT, prior shoulder arthroplasty, and a history of smoking with extended oral antibiotic prophylaxis or another suitable alternative.

Optimizing patients before surgery extends beyond just STT. Using a large dataset, Boddapati *et al*. prospectively collected 30-day outcomes to determine the relationship between revision TSA and primary TSA postoperative complications. From this, they identified wound infections to be significantly more common in revision TSA compared to primary TSA. Patients with a history of smoking served as a significant independent risk factor in the development of postoperative wound infections, which is supported by previous literature demonstrating increase in the risk of postoperative healing complications in both orthopaedic and non-orthopaedic procedures.[49, 50] Boddapati *et al*., credited this increase in wound infections to the increased rate of *Propionibacterium* acne colonization of the shoulder, specifically mentioning that this bacterium is most commonly found in the pilosebaceous follicles of the upper body, such as the axilla, and that a prior prosthetic implant significantly increases the risk of infection.[51]

Ankle Arthroplasty

Late-stage ankle arthritis is a disabling degenerative disease of the tibiotalar joint that inflicts significant pain and causes impaired function in patients.[52, 53, 54, 55, 56] After unsuccessful nonoperative conservative management, total ankle arthroplasty (TAA) and tibiotalar arthrodesis are the two most common surgical treatment options.[57] Over the past 30 years, TAA has become increasingly more popular with the development of newer implant designs and improved surgical techniques. Karzon *et al*. performed a retrospective database review and identified a total of 41,060 TAAs performed from 2009-2019, where annual volumes increased by 136.1% from 2,180 in 2009 to 5,147 in 2019.[52] From 2017-2030, the incidence of TAAs has been projected to increase from 110% to 796%.[57] A systematic review from Vale *et al*. observed a mean complication rate of 23.7% for TAA, where the postoperative complications from highest to lowest incidence were aseptic loosening, intraoperative fracture, implant failure, and wound problems.

As evident from this review, preoperative radiographic STT has been suggested as a predictor outcome following hip, knee and shoulder arthroplasty. To date, only one study has explored radiographic STT as a predictive metric for identifying patients at risk of requiring revision surgery following primary TAA. Wu *et al*. performed a retrospective comparative study on 323 patients who underwent primary TAA between 2003 and 2019 (Table 4).[58] Preoperative tibial tissue thickness was calculated as the distance from the posterior distal tibia to the anterior distal tibia, and preoperative talus tissue thickness was calculated as the distance from the lateral process of the talus to the head/neck junction of the talus. In patients who required revision surgery there was greater preoperative tibial and talus tissue compared to those not requiring revision. Furthermore, a multivariable logistic regression controlling for age, gender, BMI, American Society of Anesthesiologists (ASA) classification, diabetes status, smoking status, primary diagnosis, and implant type demonstrated that both tibial tissue and talus tissue were significant predictors of revision surgery with tibial tissue thickness being the stronger of the two.

Implant malalignment may offer an explanation for STT being a predictor for revision following primary TAA. Implant malalignment can result in elevated edge loading, polyethylene wear, bearing subluxation, and premature failure of primary TAA. Additionally, malalignment can exacerbate any uneven distribution of force in the bone.[59, 60] A retrospective study from Richter *et al*. examined primary TAA using a single-design three-component ankle implant in 1,006 patients. The cumulative incidence of implant revision was 9.8%, and the most common indication for revision was instability at 34%. In this study, instability was defined as the progressive varus/valgus malalignment of the hindfoot and/or coronal malalignment of the talus in the ankle mortise.[61] Furthermore, a study from Clough *et al*. reported the clinical and radiological outcomes for 200 TAAs using the Scandinavian Total Ankle Replacement (STAR) implant. Edge-loading of implants from coronal plane malalignment (varus or valgus) was the reason for revision surgery in 25% of patients. Three of their patients were required to have the polyethylene components exchanged due to excessive wear, and one patient was ultimately converted to an ankle fusion due to a late stress fracture that resulted in malalignment.[62]

Increased STT could pose a challenge for proper alignment, as the increased thickness may result in orthopaedic surgeons experiencing a higher degree of surgical complexity when properly positioning the implant within the ankle joint and performing soft tissue balancing. To this point, increased STT at the surgical site could impair visualization of the surgical field, further increasing surgical complexity when attempting to achieve proper alignment. A key limitation to address between the ankle joint in comparison to the hip and knee specifically, is the difference in soft-tissue coverage. Previous literature has underscored the importance of sufficient soft tissue coverage of the prosthesis in managing wound healing complication.[63] The ankle joint has significantly less soft tissue coverage compared to the hip and knee, and hence could affect the risk of complications following TAA. This reduced coverage means that while increased STT has been demonstrated to be predictive of complications in other lower-extremity arthroplasty, the specific anatomical characteristics of the ankle could alter these dynamics and warrants further research exploring this in greater depth. Overall, patients who experience greater STT may benefit from strategies aimed at managing the impact of STT on proper implant alignment through preoperative planning and intraoperative techniques.[64]

Measurement Considerations

Inter-rater reliability pertains to consistency of measurements between multiple raters, and intra-rater reliability refers to consistency of measurements between an individual rater. Inter- and intra-rater reliability is important in the ability to replicate results and can be quantified using coefficients – examples include intra-class correlation (ICC) and Pearson (*r*)[65]. In pre-operative planning, this is important, as lower reliability may cause inaccurate mapping and registration of anatomical landmarks, and thus leading to improper positioning of prostheses[66].

The ability to make accurate and repeatable measurements is often limited by the radiographs obtained. As discussed in prior sections, positioning of patients may affect measurements. In addition, presence of inflammation and hematoma may affect STT and other metrics[36]. Standard positioning and calibration practices may mitigate some discrepancies in radiographs.

Due to the variation in measurement methodology of STT, a standardized measurement technique may prove beneficial. For THA, STT measurements that have been described encompass taking distances between two structures or using radiographic lines and various ratios. For TKA, measurements also vary across studies, ranging from measuring thicknesses (*i.e.* prepatellar thickness, pre-tubercular thickness, anterior STT, medial STT) to ratios (*i.e.* prepatellar fat thickness ratio, knee adipose index, periarticular soft-tissue index, lower extremity girth)[36].

Future Directions

STT has shown promise as a potential predictive tool for complications after total joint arthroplasty. However, accurately measuring the soft tissue is essential for respective validity and reliability. Accurate and consistent measures of STT allow for proper guidance in surgical planning and may help in understanding patient outcomes, allowing for enhanced preoperative patient counseling and expectation management. Measurements of STT have the potential to significantly enhance clinical decision-making by being integrated into existing clinical pathways. For example, incorporating STT indicators could help identify patients at higher risk for pressure ulcers or wound complications, allowing for early intervention and tailored management plans. Additionally, STT measurements could inform surgical planning by helping to customize treatment approaches based on individual soft tissue characteristics, improving outcomes and reducing complications. Overall, using STT data in risk assessment and patient management could lead to more personalized and effective care strategies.

Integrating artificial intelligence (AI) in preoperative assessment is a promising aspect for further research. Further resources and research with AI capability have shown its capabilities in analyzing image data at an accurate, reliable, and timely rate[67,68]. Therefore, AI can be a potential avenue to provide an accurate and precise way to deconstruct the complexity of the soft tissue envelope surrounding the joints. Additionally, redefining and standardizing current measurement techniques is essential for producing accurate and reproducible metrics. Additionally, developing ratios or indexes that account for individual baseline size in evaluating soft tissue distribution compared to simple measurements alone can make these metrics more accurate. Several ratios and indices have been proposed to account for variations in tissue distribution. In TKA patients, Wagner *et al*. examined a ratio comparing prepatellar fat to the patella itself to account for patient size[23]. Similarly, Secrist *et al*. investigated the LEG ratio in TKA. In RSA, Wu *et al*. used a ratio comparing the size of the deltoid radius to the humeral head[48].

Several studies have explored the use of AI to evaluate various body parts including musculoskeletal structures[69,70,71]. Ning *et al*. employed a network model to accurately measure plantar soft tissue thickness in weight-bearing foot X-rays, demonstrating its potential for assessing foot health[72]. Additionally, foundation models have been explored as a possibility to address complex segmentation[69, 71, 73]. Foundation models are neural networks trained on vast data using creative learning objectives, enabling them to perform zero-shot learning on new data without traditional labels[71]. They have shown transformative abilities in natural language processing and demonstrated promising segmentation performance. For example, Gu *et al*. recently developed a deep-learning model using 8485 annotated slices to segment bone within MRI images[73]. These developments and models can be developed in the future to include STT and provide risk stratification.

Future studies should be implemented, ideally across multicenter samples, to fully enhance the clinical utility of measurements of STT and establish reliable and standardized protocols and thresholds. This additional research will optimally allow for confident and effective preoperative planning and risk stratification for TJA patients when STT is measured and used. Utilizing advanced imaging modalities can be a way to provide more detailed and consistent measurements. CT, already used in spine surgery to assess STT, can be further investigated for TJA[74]. CT scans can provide a more reproducible measurement of soft tissue around the joints. Future research must investigate whether CT scans can provide a better predictive measure for postoperative complications.

CONCLUSION

This comprehensive review highlights the significance of preoperative STT as a predictive measure for complications following arthroplasty procedures, including total knee, hip, shoulder, and ankle replacements. The findings across studies generally indicate that increased STT is often associated with higher risks of postoperative complications such as infections, wound healing issues, and SSI. These complications can lead to extended hospital stays, increased healthcare costs, and the need for further surgical interventions. While BMI has traditionally been used to assess patient risk, it falls short in accurately representing local tissue composition relevant to specific joints. In contrast, STT provides a more precise measure, particularly with advancements in radiographic techniques such as MRI and CT scanning that allow for detailed preoperative assessment.

Several studies have demonstrated that STT is a reliable predictor of complications, offering valuable insights for preoperative planning and patient management. However, variability in measurement methodologies and the need for standardized techniques highlight the necessity for further research. The integration of AI in analyzing STT could revolutionize preoperative assessments by providing accurate and timely evaluations of the soft tissue envelope surrounding the joints. Continued research is essential to refine these methods and fully realize the potential of STT in guiding preoperative planning and optimizing arthroplasty results.

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