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GENERAL ORTHOPAEDICS

Malnutrition in total joint arthroplasty: what should the orthopaedic surgeon consider?

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- Total joint arthroplasty (TJA) is rising globally, with an associated increase in associated complications, necessitating increased efforts in prevention of these complications with pre-operative optimisation.
- Malnutrition has been highlighted as one of the most important pre-operative modifiable risk factors to be addressed in TJA, with the term malnutrition in orthopaedic surgery having a broad definition that encompasses a wide range of nutritional abnormalities from undernutrition to overnutrition contributing to the outcomes of TJA.
- Complications associated with malnutrition include periprosthetic joint infection (PJI), periprosthetic fracture, dislocations, aseptic loosening, anaemia, prolonged length of stay (LOS), increased mortality, and raised health care costs.
- Standardised nutritional scoring tools, anthropometric measurements, and serological markers are all options available in pre-operative nutritional assessment in TJA, but there is no consensus yet regarding the standardisation of what parameters to assess and how to assess them.
- Abnormal parameters identified using any of the assessment methods results in the diagnosis of malnutrition, and correction of these parameters of overnutrition or undernutrition have shown to improve outcomes in TJA.
- With the multiple nutritional parameters contributing to the success of total joint arthroplasty, it is imperative that orthopaedic surgeon has a thorough knowledge regarding nutritional peri-operative optimisation in TJA.

Keywords: malnutrition; total hip arthroplasty; total knee arthroplasty; pre-operative optimisation

Introduction

Total joint arthroplasty (TJA), including total knee arthroplasty (TKA) and total hip arthroplasty (THA), has reported survivorship at 10 years of 95%, justifying TJA as the optimal surgical procedure for end-stage degenerative joint disease (1, 2). Over 2 million TJAs are performed annually, with a predicted increase of 145% for THA and 147% for TKA within the next decade (3, 4).

The global rise in TJA has a predicted paralleled increase in associated complications (5). This has necessitated an increased effort to prevent post-operative complications by identifying and addressing pre-operative modifiable risk factors (5, 6, 7). There has been a significant increase in publications regarding malnutrition in orthopaedic surgery over the last 6 years, alluding to the importance of peri-operative nutritional assessment and optimisation in TJA patients (8). Assessment of malnutrition is a key component in the pre-operative evaluation in TJA (9, 10, 11, 12). Johnson *et al.* (13) reviewed 84 315 patients and found that malnutrition

EFORT Open Reviews (2024) **9** 615–624
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was the strongest risk factor for poor post-operative outcomes in TJA. Multiple publications highlight that malnutrition results in numerous post-operative complications including but not limited to periprosthetic joint infection (PJI), aseptic loosening, periprosthetic fracture, dislocation, anaemia, prolonged length of stay (LOS), and TJA 90-day total cost, and an increase in mortality (7, 8, 12, 13, 14, 15).

Definition

The term malnutrition, with its broad definition, has been used extensively in orthopaedic literature (16). Malnutrition includes acute, subacute, or chronic states of nutrition with various aspects of both overnutrition or undernutrition, with or without an element of inflammation, leading to altered body composition and function (16, 17, 18). Ultimately, there is an imbalance of macro- and micro-nutrients and energy consumption (19). The definition and diagnosis of malnutrition are multifactorial, with no consensus regarding the methods used to screen and diagnose malnutrition in orthopaedic surgery (14, 16, 20, 21, 22). This has hindered the standardisation of assessing and diagnosing malnutrition in TJA, although it has been suggested by the Joint Commission that pre-operative nutritional screening should be performed within 24 h of admission for patients undergoing surgery (10, 23, 24).

There have been numerous recommendations that all arthroplasty patients should undergo pre-operative nutritional assessment, but the details of what and how to assess remain debatable, with some even arguing that only patients with risk factors for malnutrition should be assessed (9, 11, 23, 24, 25). It should not be overlooked that various aspects of a patient's nutritional status affect the success of TJA, and knowledge regarding these aspects is essential for optimal pre-operative optimisation in TJA (10, 11, 12).

Epidemiology

Due to the heterogeneity of definitions available and the lack of a gold standard in malnutrition assessment, there has been a wide range in the prevalence of malnutrition reported (26, 27). The prevalence of malnutrition in the adult population has been reported to range from 15% to 60% (18). In patients undergoing TJA, the prevalence of malnutrition has been reported to range from 8.5% to 50% (10, 17, 26, 28).

Nutritional evaluation

A variety of methods have been proposed to diagnose and define malnutrition, including standardised nutritional scoring tools, clinical anthropometric criteria, and serological laboratory values (9, 12, 29, 30). The clinical signs and symptoms of malnutrition may be subtle and often undetected until there has been severe progression of malnutrition; therefore, a combination of assessment methods has been proposed to evaluate nutritional status (10, 18, 29). The most effective measure of nutritional status includes a comprehensive history and clinical examination in combination with laboratory serological markers (31). Malnutrition is diagnosed when any of these assessment methods identify abnormal parameters (12). Multiple co-morbidities, as well as the Charleston Comorbidity Index and the American Society of Anesthesiology classification, are associated with malnutrition (25, 32). Increased age, a history of gastrointestinal pathology, a history of malignancy, and alcohol abuse predispose patients to an increased risk of malnutrition (7). This highlights the holistic approach necessary for pre-operative optimisation, with the assessment of malnutrition beginning with a thorough medical history identifying co-morbidities (25, 27).

Standardised nutritional scoring tools

There are numerous standardised nutritional scoring tools, combining subjective history and clinical assessment, with some utilising laboratory serological markers (9, 17, 33) (Table 1). These tools focus more on identifying patients with nutritional deficiency as opposed to overnutrition.

The mini nutritional assessment (MNA) is useful in identifying patients who would benefit from nutritional intervention and has been suggested as the first-choice nutritional scoring tool due to its association with serum albumin and LOS (24, 27, 34). Ihle *et al.* (35) evaluated the MNA in a prospective study on 351 TJA patients and found that inferior scores related to unfavourable LOS, post-operative mobilisation, and the incidence of adverse events. Guo *et al.* found the MNA useful in predicting patients with delayed wound healing, and the MNA has been reported as the most reliable of the nutritional scoring tools (10, 34).

Koren-Hakim *et al.* (36) compared the adequacy of nutritional tools in the assessment of malnutrition in patients with hip fractures requiring TJA and found that the MNA, Malnutrition Universal Screening Tool (MUST) and the Nutrition Risk Screening 2002 (NRS-2002) were adequate; however, only the MNA predicted poor outcomes such as re-admission rates and mortality. O'leary *et al.* (37) reported that the MUST score, which identified patients at risk of malnutrition, predicted short- and medium-term mortality, LOS, and discharge destination for patients admitted for hip fractures. The MUST has been recommended by the National Institute for Health and Care Excellence for screening adult patients admitted to the hospital, and in 2017,

EFORT Open Reviews (2024) **9** 615–624
https://doi.org/10.1530/EOR-23-0192

Table 1 Summary of standardised nutritional assessment (SNA) tools.

SNA score	Subjective assessment	Anthropometric data	Laboratory data	References
MNA	Weight loss, dietary intake, fluid intake, patient mobility, patient independence, self-perception	BMI, calf circumference, mid arm circumference	NA	9,14,16,38
MNA- SF	Weight loss, dietary intake, mobility, psychological stress	BMI, calf circumference	NA	16,34
MUST	Changes in weight, dietary intake	BMI	NA	16,34
NRS-2002	Changes in weight, changes in dietary intake in presence of illness	BMI	NA	34
PONS	Changes in weight, dietary intake	BMI	Albumin, vitamin D	9

MNA, Mini Nutritional Assessment; MNA-SF, Mini Nutritional Assessment short form; MUST, Malnutrition universal screening tool; NRS-2002, Nutrition Risk Screening 2002; PONS, Perioperative Nutrition Screen.

it was the most commonly used nutritional screening tool used to collect data for the National Hip Fracture Database in the UK (37). The NRS-2002 was used by Shang *et al.* (38) to identify patients at nutritional risk when reviewing 1532 patients undergoing TJA, and found that those with nutritional risk were at increased risk of wound complications, surgical site infections, PJI, cardiac complications, respiratory complications, urinary complications, and had increased total cost and LOS. There is less published evidence on the use of the Peri-operative Nutrition Screen (PONS) in orthopaedic surgery; however, the PONS is a modified version of MUST (15). Vitamin D and albumin are well-documented markers of malnutrition in arthroplasty surgery, which are utilised in the PONS (10).

Clinical anthropometric criteria

Anthropometry measurements used in orthopaedic literature (Table 2) include body mass index (BMI), mid-upper arm circumference (MAC), calf circumference (CC), triceps skinfold thickness (TST), and suprapatellar index (SI) (30, 39) (Table 3). Anthropometry measurements are less routinely documented in orthopaedic literature except for BMI (9, 14). Abnormal anthropometric parameters have been associated with post-operative complications and increased LOS in orthopaedic surgery (30). Anthropometric measurements are used as indirect measurements of nutritional status and should not be used to assess marginal or acute malnutrition (40). They have the advantage of being cheap and easy to perform, with some forming part of the standardised nutritional scoring tools mentioned above (9).

The use of the TST has not been extensively reported in the orthopaedic literature for nutritional assessment (9). Font-Vizcarra *et al.* found that TST was associated with the risk of infection in a prospective study of 213 patients undergoing TKA (41). There was a 5% risk of infection and a 10% risk of infection with a TST of 3 cm and 2 cm, respectively (41). Reduced CC and MAC are related to decreased muscle mass and loss of subcutaneous fat, with MAC more commonly utilised due to ease of use in hospitalised patients (30). Using CC or MAC is not well-reported in TJA; however, both are included in the MNA, which has been used in identifying patients with malnutrition in TJA (10, 34).

SI is an anthropometric measurement used in TJA and related to BMI, although it has not been used directly as an assessment of malnutrition (39). The distribution of adiposity has been noted to be important in determining infection risk and wound healing, especially in TKA (39). SI is calculated by dividing the length of limb by the circumference of the limb 4 cm above the superior pole of the patella, with a ratio of <1.6 indicating a shorter and wider limb and increased soft tissue around the distal thigh (39). Lozano *et al.* found that an SI of <1.6 more accurately predicted prolonged tourniquet time and increasing surgical difficulty in TKA (P < 0.038) compared to using BMI alone (39).

Table 2 Summary of anthropometric measurements.

Anthropometric data	Abnormal value	References
MAC	<22 cm	23, 38
CC	<31 cm	8, 23, 26
TST	<5 mm	26
SI	<1.6	39
BMI	<18.5 kg/m^2 and >25 kg/m^2	10

BMI, body mass index; CC, calf circumference; MAC, mid-upper arm circumference; TST, triceps skinfold thickness; SI, suprapatellar index.

Table 3 WHO classification of body mass index (BMI) (40).

BMI, kg/m^2	Classification
<18.5	Underweight
18.5–24.9	Normal range
25–29.9	Overweight (pre-obese)
30–34.9	Obese class I
35–39.9	Obese class II
>40	Obese class III

EFORT Open Reviews (2024) **9** 615–624
https://doi.org/10.1530/EOR-23-0192

Body mass index

BMI is an important clinical assessment tool (9, 12, 24). It is the most commonly used anthropometric measurement in TJA (30). It is calculated by dividing weight in kilograms by the square of height in metres (24). The World Health Organization (WHO) has divided BMI into categories (Table 3) (42). The flaw in BMI is that it does not consider soft-tissue distribution or muscularity; however, assessing BMI is critical in nutritional assessment in TJA (12, 43). Both low BMI (<18.5 kg/m^2) and high BMI (>30 kg/m^2) form part of the broad definition of malnutrition and are independent predictors of adverse events in TJA (10, 24). Studies have further shown that different BMI classes are associated with different complications (44).

Increased BMI

Obesity, defined as BMI >30 kg/m^2, is well-documented as a significant modifiable risk factor in TJA (45). It forms part of the overnutrition aspect of the definition of malnutrition associated with a change in body composition and often with other co-morbidities (5, 46). The prevalence of obesity is rising, with more than 502 million people being diagnosed as obese, and it is predicted that more than 46% of Americans will be obese by 2029 (5, 47). Obesity has been shown to be associated with osteoarthritis, especially of the knee, with the risk for osteoarthritis in obese patients reported to be four-fold higher and five-fold higher in males and females, respectively (5, 7, 47, 48). The exponential increase in the rate of obesity recently has coincided with an increased demand in TJA (45, 47, 49). By 2029, more than 55% of patients requiring THA will be classified as obese (47).

The TJA complications associated with obesity include surgical site infections, PJI, component malpositioning, component failure, revision arthroplasty, 10-year mortality, longer surgical duration, and increased LOS (7, 12, 45, 50, 51). The odds ratios for major complications increase to 8× and up to 25× when BMI is over 40 kg/m^2 and 50 kg/m^2, respectively (5). This is in keeping with Zusmanovich *et al.* (45), who found after reviewing 268 663 patients that these complications have a stepwise increase paralleled to increasing BMI, highlighting the importance of reducing BMI prior to TJA.

The rate of PJI in the USA, although still low, at least doubled in both TKA and THA between 1998 and 2011 when comparing TJA in the obese and non-obese population (52). This can increase by up to fourfold in morbidly obese patients (53). The risk of dislocations, even in correctly positioned prosthesis in THA, is more than 4× higher in obese patients (54). Increasing LOS linked to obesity is associated with other complications such as venous thromboembolism and rising health costs (55). Every 5-unit increase in BMI beyond 30 kg/m^2 is associated with $500 higher hospital costs and $900 higher 90-day costs (55).

Although complications are associated with increasing BMI, a specific BMI cut-off prior to surgery has not been agreed upon (56). Ward *et al.* found that BMI >40 kg/m^2 was an independent risk factor for complications such as acute kidney injury, cardiac arrest, infection, and revision surgery (49). Optimising BMI to <40 kg/m^2 and/or aiming for at least 5–10 % weight loss has been strongly suggested (5, 17, 45, 47, 51, 57). There is no consensus regarding the optimal weight loss strategy for pre-operative optimisation, with options including nutritional specialist consults, weight loss programmes, pharmacotherapy, and bariatric surgery (BS) (12, 45, 51, 57). Non-surgical weight loss techniques have been reported to result in reduction of approximately 3 kg/m^2 (56).

BS can result in a total mean weight loss exceeding 31%, although its use in TJA remains controversial as malabsorption secondary to the procedure may lead to other complications (17, 47, 58). BS techniques include gastric banding, Roux-en-Y, and sleeve gastrectomy (56, 59). The average weight loss with the use of bariatric surgery prior to TJA is approximately 14 kg/m^2 (56). Sax *et al.* (59) reviewed national databases in the USA over a 10-year period and found that there was no significant difference in complications and outcomes between the timing and type of BS used prior to TJA. In a meta-analysis by Li *et al.*, statistically significant improvements in LOS, short-term complications, and operative time in morbidly obese patients undergoing BS were documented (46). No difference in long-term complications was found, including dislocation, periprosthetic fracture, PJI, and revision surgery (46). This is in keeping with the systematic review by Smith *et al.* (60) , which found that BS reduces weight but does not significantly reduce complications or improve outcomes in TJA. The risk of TJA in obesity versus the risk of undergoing BS to reduce BMI requires further careful evaluation, and risk stratification may be necessary.

Obese patients have surprisingly been found with paradoxical malnutrition, with deficiencies in serum albumin, vitamin D, vitamin C, zinc, thiamine, selenium, and iron (12, 32, 57). Huang *et al.* reviewed 2161 arthroplasty patients for malnutrition using laboratory markers and found that 42.9% of obese patients were malnourished (32). This highlights the point of using multiple aspects of nutritional assessment in TJA patients, as concomitant deficiencies in nutrition increase the risk of complications (12).

Decreased BMI

Underweight (BMI <18.5 kg/m^2) has been associated with increased complication rates similar to obesity (10, 61). There is less published data on the risk of underweight compared to obesity in TJA, most likely due to underweight patients representing a smaller proportion of the population (61). In the USA, 1.5 % of the population are patients who are classified as

EFORT Open Reviews (2024) **9** 615–624
https://doi.org/10.1530/EOR-23-0192

underweight (61). Underweight patients have been noted to have compromised immune systems and lower bone mineral densities predisposing patients to infections and fractures (12). Underweight patients have increased odds ratios (OR) for aseptic loosening (1.62), periprosthetic fractures (1.5), and dislocation (1.8), with increased 2-year mortality (61, 62). Schmerier *et al.* found revisions in underweight patients were more likely to be due to periprosthetic fractures and PJI (44). Anoushiravani *et al.* compared underweight patients to patients within normal range BMI and found underweight patients were at increased risk for post-operative anaemia and cardiac complications which resulted in higher hospital costs (63). This was supported by Sayeed *et al.*, reporting that underweight patients developed complications such as post-operative anaemia, deep vein thrombosis, increased LOS, and overall increased healthcare costs (64). Although there is a paucity of information in the literature regarding nutritional interventions for underweight patients prior to TJA, additional nutritional workup has been suggested to identify and reverse other associated nutritional deficiencies (12, 24, 27).

Serological assessment

Serological markers are not part of the diagnostic criteria for malnutrition according to American Society for Parenteral and Enteral Nutrition (ASPEN) (10). In the orthopaedic literature, serological markers have been found to predict complications, and therefore have been proposed as surrogates in assessment of malnutrition, especially in the subclinical setting (9, 10) (Table 4).

Serum albumin, prealbumin, total lymphocyte count (TLC), transferrin level, vitamin D, and zinc are often used to identify malnutrition in TJA, with albumin being the most widely used (9, 11, 15, 21, 29, 30, 65). Assessment of haemoglobin may identify anaemia with associated micronutrient deficiencies of iron, folate, vitamin B12, and copper (27). Any abnormal serological parameter predisposes the patient to be at risk for complications (11). It should be noted that some of these serological markers are also negative acute phase reactants, and their interpretation should take this into consideration (18). However, this should not distract from the fact that abnormal serological parameters such as hypoalbuminaemia have independently been found to be predictors of complications in arthroplasty surgery (11).

Hypoalbuminaemia

Albumin is an essential and the most abundant protein in blood serum with many important roles. It transports a variety of fatty acids, steroids, and hormones with a half-life of 14–20 days (29, 33). Albumin has a positive

Table 4 Summary of laboratory parameters used in assessment of malnutrition.

Parameter	Role	Clinical implication	Nutritional deficiency*	Intervention	References
Visceral proteins					
Albumin	Regulates osmotic pressure; regulation of metabolic pathways; acid–base balance; tansport protein; immune function; collagen synthesis	PJI; wound complications; increased LOS; increased 90-day readmission; anaemia	<35 g/L	Protein supplementation: 1 g/kg or 100 g daily	10, 11, 13, 19, 28, 29
Pre-albumin	Serum transport protein for thyroid hormone, transthryetin	Wound complications	<10–15 mg/dL		29, 31
Transferrin	Serum transport protein for iron assessment	Wound complications	<200 mg/dL		8, 10, 21, 29, 31
Total lymphocyte count	Immune system function	PJI; wound complications; prolonged functional recovery	<1500 cells/mm^3		10, 29
Trace elements and vitamins					
Vitamin D	Homeostasis of bone, calcium and phosphate; immune system function	PJI; increased LOS; periprosthetic fractures; osteoporosis	<50 mmol/L or <20 ng/mL	5000 IU p.o. daily (11) or 50 000 IU weekly	10, 11, 14, 16, 23
Zinc	Immune system function	PJI; wound complications	<95 µg/dL	220 mg zinc daily	16, 23
Iron	Production of haemoglobin	Anaemia	< 60 µg/dL	324 mg iron TDS	11, 16, 64

*Values used to identify nutritional deficiency.

EFORT Open Reviews (2024) **9** 615–624
https://doi.org/10.1530/EOR-23-0192

effect on the immune system with its involvement in antigen presentation to T-cells, lymphocyte proliferation, antibody responses, interleukin-2, and interferon-gamma (17). Because of these multiple roles, the relationship between hypoalbuminaemia and post-operative complications such as PJI is multifactorial (29).

Hypoalbuminaemia (<35 g/L) in TJA has been reported to be associated with superficial surgical site infections, pneumonia, unplanned intubation and prolonged ventilation, higher blood transfusion rates, sepsis, and increased mortality (8, 14, 17, 31, 66). In a retrospective study of 65 023 and 108 556 patients undergoing THA and TKA, respectively, Fryhofer *et al.* found hypoalbuminaemia was a significant independent risk factor for adverse outcomes (65). Bala *et al.* showed that hypoalbuminaemia is a significantly increased risk factor for pulmonary embolism, stroke, myocardial infarction, heart failure, acute renal failure, respiratory failure, and sepsis in patients undergoing TJA (14). In the review by Loftus *et al.*, using hypoalbuminaemia or nutritional risk score (NRS) to diagnose malnutrition, it was reported that surgical site infections were the most common reported complication followed by increased LOS and increased costs (31). Albumin has been suggested to be better than using BMI, with hypoalbuminaemia a more significant risk factor for post-operative complications than obesity (24, 28). Albumin is a nutritional marker of protein–energy malnutrition (PEM) and has been associated with chronic disease but is also an acute-phase reactant (12, 17, 29, 65). There are several disease states that affect albumin and pre-albumin levels including liver disease, catabolism, nephrotic syndrome, and protein-losing enteropathy (31). In the acute phase of inflammation, the liver decreases production of albumin and pre-albumin in order to produce acute-phase reactants (31). This needs to be taken into consideration with caution when interpreting results of albumin and pre-albumin in the presence of chronic disease states or inflammatory processes (17, 31).

Hypoalbuminemia is a modifiable risk factor for post-operative complications and a marker of ‘nutrition risk’, specifically PEM (67). Once hypoalbuminemia is identified, referring to a nutritional specialist is useful, as increasing albumin can be approached with direct therapy using IV human albumin administration or indirectly with parental or enteral protein supplementation (12, 13, 24, 65). Enteral nutritional supplementation has a significant amount of data proving its efficacy in reducing TJA complications (12, 26). Studies where protein supplementation has been given peri-operatively, increasing daily protein intake, have resulted in fewer post-operative complications (17). Schroer *et al.* (68) found that prescribing a high-protein (100 g/day) peri-operative diet in patients identified as malnourished with hypoalbuminaemia improved surgical outcomes in TJA. Patients with hypoalbuminaemia can be referred to the relevant practitioners and optimised pre-operatively by targeting an intake of at least 1 g/kg daily (17).

Pre-albumin

Pre-albumin is used as a nutritional marker with the advantage of having a shorter half-life compared to albumin (2–3 days), therefore is useful in acute nutritional state changes (30, 33). There is no official value for pre-albumin level to be used as a marker for malnutrition in TJA (24). Pre-albumin levels are affected by renal and liver function, infection, stress, and hydration status (30, 33). Serum pre-albumin has been suggested not to be used specifically as a nutritional marker for PEM but rather as a measure of ‘nutritional risk’ (67).

Transferrin

Transferrin is an acute-phase reactant with a half-life less than that of albumin at ±10 days (9, 33). Serum levels decrease in the setting of severe malnutrition but may also be affected by renal failure, liver disease, and iron status (22, 33). Transferrin, together with albumin, is utilised in the Rainey-MacDonald Nutritional Index (RMNI), used in screening for malnutrition (9, 69). It has been shown to be a better predictor of outcomes than using TLC (24). With nutritional intervention, serum transferrin has noted to improve similarly to the management of hypoalbuminaemia (33).

RMNI = (1.2 × serum albumin) + (0.013 × serum transferrin) − 6.43 (69).

Total lymphocyte count

In malnourished states, PEM may negatively impact the maturation of lymphocytes, resulting in a decrease in the TLC below 1500/mm^3 (33). Assessment of TLC can be used to support PEM; however, it is not specific (33). TLC is a less reliable predictor of post-operative complications compared to albumin and should be used as a supplemental measurement of nutritional status (9, 14). TLC has been shown to predict complications post-TJA, as abnormal serum albumin and TLC are associated with increased mortality in TJA following hip fractures (12).

Zinc

Zinc is the second most abundant trace element in the body after iron (70). There is a paucity of evidence regarding the assessment of perioperative zinc deficiency in TJA (9, 71). Zinc deficiency has been noted to affect the competence of the immune system, including innate and adaptive immunity (17). Low pre-operative zinc levels (95 µg/dL) have been associated with delayed wound healing in orthopaedic surgery (24, 70, 71). Complications arising from delayed wound healing are potentially devastating, ranging from superficial wound infections to wound dehiscence and

EFORT Open Reviews (2024) **9** 615–624
https://doi.org/10.1530/EOR-23-0192

PJI (70). Assessing pre-operative zinc levels in TJA and providing supplementation may aid in decreasing the risk of these complications (17, 24, 70). More research needs to be done in terms of the role of zinc and its deficiency in TJA.

Vitamin D

Vitamin D deficiency has been noted even in healthy populations, with a prevalence of 41.6% (7, 24, 72). Vitamin D is essential in the homeostasis of bone, calcium, and phosphate, and its immunomodulatory effects play a significant role in both innate and adaptive immunity (12, 17). According to Khoo *et al.*, vitamin D has been shown to have an effect on immune and cell-signaling pathways (73). Vitamin D deficiency is associated with increased rates of PJI following primary TJA, with Maier *et al.* reporting that 86% of patients undergoing revision surgery for PJI had vitamin D deficiency (7, 72). Traven *et al.* found that patients with hypovitaminosis D were more likely to have a 90-day complication, with 13% of these patients needing revision surgery compared to patients with normal vitamin D levels (74). Additionally, these patients were more likely to experience infectious complications when compared to patients with normal vitamin D levels ($P < 0.001$) (74).

Although there is limited evidence to support vitamin D as a standard marker in assessing nutritional status, vitamin D is an important modifiable risk factor in the orthopaedic setting, with the potential of correction in as little as 1 month (7, 24, 75). Arshi *et al.* evaluated the costs of vitamin D supplementation prior to TKA and found that pre-operative restoration of vitamin D levels was a cost-effective way of reducing the risk of PJI in TKA (76). Maniar *et al.* (77) found that patients with hypovitaminosis D had lower pre-operative functional scores and recommended post-operative supplementation.

Vitamins and other trace elements

Iron is the most abundant trace element in the body, essential for haemoglobin (70). Deficiencies in vitamin B12, folate, and iron result in anaemia, which has been associated with poor outcomes in TJA (17, 30). Obese patients have also been found to be deficient in vitamin C, thiamine, and selenium, in addition to the previously mentioned nutritional markers (12). Vitamin C alone has been noted to be an important nutritional parameter with its anti-oxidant, immunostimulant, anti-viral, and anti-bacterial properties (17, 78). Simple interventions would include supplementation of iron and vitamin C (17). The relationship between obesity and diabetes mellitus should also not be overlooked, and assessing haemoglobin A1c (HbA1c) should be part of the pre-operative workup with the goal of achieving HbA1C <7 % (9, 12).

Management of malnutrition in arthroplasty

There is no standardised approach to treating malnutrition in TJA, probably due to the broad use of the definition (11, 27). Once malnourished patients are identified, they should be referred to the relevant health disciplines for treatment and pre-operative optimisation with targeted supplementation (11, 13, 16, 79). This process of identifying and managing patients with malnutrition should involve a collaborative effort between the orthopaedic surgeon, primary care physician, and nutritional specialist (27). The intervention depends on the type of malnutrition identified, as discussed previously under the relevant headings (57).

Nutritional supplementation directed at identified deficiencies improves malnutrition and reduces post-operative complications (14, 15). It has been noted in previous studies that malnutrition has been underrecognised, limiting the referral to optimise nutritional status, and this needs to be improved (16). Both trauma and non-trauma patients undergoing TJA, who have been identified for pre-operative optimisation of nutrition and received supplementation, have been shown to benefit (65). Williams *et al.* (2020) report implementing a perioperative enhancement team, with screening beginning with the PONS, and patients identified as malnourished follow the high-risk nutritional pathway and are given a high-protein diet and nutritional supplements (15). The first step in the correct management of malnutrition is adequate screening and diagnosis.

Conclusion

Malnutrition is a broad term that includes many abnormalities of nutritional status; however, in the orthopaedic literature, BMI and albumin are commonly used parameters to assess and address malnutrition. Understanding and identifying abnormal nutritional parameters are fundamental in the process of addressing malnutrition in TJA. Malnutrition is multifactorial, and a multidisciplinary and holistic approach is required to identify and reverse the various abnormal nutritional parameters. The ultimate goal in TJA is a successful procedure with no complications and optimising these nutritional parameters will aid in improving the success of TJA.

ICMJE Conflict of Interest Statement
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EFORT Open Reviews (2024) **9** 615–624
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