Preoperative Nutrition and General Health Concerns, Patient Indications, and Selection Criteria

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2.1 Preoperative Nutrition: Effect of Malnutrition on Total Joint Arthroplasty Outcomes

Malnutrition is a state of altered body composition and function resulting from a lack of nutritional uptake or intake [1] that has been identified from 6% [2] to 26% of total joint arthroplasty patients [3]. Before total knee arthroplasty (TKA), malnutrition is typically defined by serum protein values of albumin (<3.5 g/dL), prealbumin (<16 mg/dL), transferrin (<200 mg/dL), and total lymphocyte count (<1500 cells/mm^3). Albumin is the most widely used marker in orthopedic surgery [4]. It is one of the most abundant proteins that transports fatty acids, steroids, and hormones and is an essential component of serum that plays a crucial role in wound healing and immune function. Patients with low albumin are likely to also lack other important vitamins that are essential for wound healing and proper immune function. They are also more likely to have comorbidities such as liver disease, cardiac disease, and renal malfunction that are associated with higher post-TKA complication rates [5, 6] and hospital charges [7]. Many investigations have reported strong correlations between a low albumin level (<3.5 dg/L) and postoperative total joint arthroplasty complications [5, 6, 8–13].

Prealbumin is a protein synthesized in the liver that is used to formulate other proteins and is also important to assay prior to surgery to determine the nutritional status of the patient. A low level (<16 mg/dL) is indicative of a number of medical conditions including malnutrition, liver disease, digestive disorders, low diet zinc, and hyperthyroidism. Prealbumin reflects short-term changes in nutritional status

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and is a more reliable test than serum albumin levels that provides a longer-term assessment. This test has become a standard at joint replacement centers. A serum globulin test may be ordered to assay a patient's overall nutrition and more specifically to diagnose any medical conditions related to the immune system. The normal range for serum globulin is 2.0–3.5 g/dL. Other factors that play a role in immune system function identified in arthroplasty patients include vitamin D, serum zinc, and adiposity [14]. Obesity, low body mass index (BMI), prior gastric bypass, malabsorption states, and hypermetabolic states may also increase the risk of malnutrition.

A systematic review of 20 studies concluded that serologic preoperative malnutrition led to deteriorated postoperative outcomes and increased complications after joint arthroplasty, including increased rates of infection and wound healing problems [10]. Albumin levels were reported in all 20 studies; ninety percent showed a correlation between low albumin content and poorer outcomes, and the authors' meta-analysis indicated that a level <3.5 dg/L had increased odds of developing a postoperative wound complication (odds ratio [OR], 2.18; 95% confidence interval [CI] 1.92–2.47). Roche et al. [13] in a study of 161,625 TKAs reported that patients with low preoperative levels of albumin (<3.5 g/dL), prealbumin (<16 mg/dL), and transferrin (<200 mg/dL) had increased odds of sustaining postoperative complications compared with patients with normal serum protein values (Table 2.1).

Bohl et al. [6] in a study of 49,603 total joint arthroplasty patients reported that compared with patients with normal preoperative albumin concentration, patients with levels <3.5 g/dL had an increased risk for any complication (7.3% vs. 4.0%; relative risk [RR], 1.5; 95% CI 1.2–1.7, $P < 0.001$), for a serious complication (2.1% vs. 1.2%; RR, 1.4; 95% CI 1.0–1.9, $P < 0.05$), for surgical site infection (2.29% vs. 0.96%; RR, 2.0; 95% CI 1.5–2.8, $P < 0.001$), and for pneumonia (1.27% vs 0.30%; RR, 2.5; 95% CI 1.6–4.0, $P < 0.001$). Nelson et al. [12] analyzed 37,143 TKAs and reported multiple statistically significant associations between low albumin and postoperative complications (Table 2.2).

In a study of 1911 total joint arthroplasty patients, Huang et al. [11] reported that malnourished patients (low albumin <3.5 mg/dl or transferrin <200 mg/dl) had a significantly higher risk of any complication compared with normal nourished individuals (12.0% and 2.9%, respectively, $P < 0.001$), as well as a significantly longer

Table 2.1 Odds of sustaining postoperative complications in patients with preoperative malnutrition compared with patients with normal serum protein values (n = 161,625 TKAs)[a]

Preoperative abnormal serum protein value	Infection OR	Wound complication OR	Concomitant infection with wound complication OR	Infection after wound complication OR
Albumin <3.5 g/dL	2.20	2.30	2.90	2.87
Prealbumin <16 mg/dL	1.87	1.90	2.27	2.22
Transferrin <200 mg/dL	1.87	1.90	1.79	1.78

OR odds ratio
[a]From Roche et al. [13]. Note: 95% confidence intervals not provided

Table 2.2 Postoperative complications related to low albumin values <3.5 g/dL (*N* = 37,143 TKAs)[a]

Complication	% Preoperative abnormal albumin	% Preoperative normal albumin	OR, 95% CI	*P* value
Any infection	5.0	2.4	2.0; 1.53–2.61	<0.001
Any major complication	2.4	1.3	1.41; 1.00–1.97	0.05
Blood transfusion	17.8	12.4	1.56; 1.35–1.81	<0.001
Pneumonia	1.21	0.29	3.55; 2.14–5.89	<0.001
Superficial surgical site infection	1.27	0.64	1.27; 1.09–2.75	0.02
Deep surgical site infection	0.38	0.12	3.64; 1.54–8.63	0.003
Unplanned intubation	0.51	0.17	2.24; 1.07–4.69	0.03
Progressive renal insufficiency	0.45	0.12	2.71; 1.21–6.07	0.01
Acute renal failure	0.32	0.06	5.19; 1.96–13.73	0.001
Cardiac arrest requiring resuscitation	0.19	0.12	3.74; 1.50–9.28	0.005
Septic shock	0.38	0.08	4.4; 1.74–11.09	0.002
Mortality	0.64	0.015	3.17; 1.58–6.35	0.001

CI confidence intervals, *OR* odds ratio
[a]From Nelson et al. [12]

length of hospital stay (>3 days, 45% and 16%, respectively, $P < 0.001$). Compared with normal nourished individuals, malnourished patients had significant increases in complications related to cardiovascular (0% and 0.5%, respectively, $P = 0.001$), neurovascular (0% and 2.7%, respectively, $P < 0.001$), renal (0.8% and 5.4%, respectively, $P < 0.001$), irrigation and debridement (0.6% and 2.7%, respectively, $P = 0.002$), hematoma (0.7% and 3.8%, respectively, $P < 0.001$), and infection within 3 months of surgery (0.4% and 2.7%, respectively, $P < 0.001$).

Blevins et al. [5] reported that low albumin was the most specific marker and had the highest positive predictive value compared with other markers (platelets, hemoglobin, and platelet-to-white blood cell ratio) in predicting infection within 2 years of total joint arthroplasty in a study of 30,863 patients. In a multivariate regression model, low albumin increased the odds of development of infection (OR, 4.69; 95% CI 2.43–9.08, $P < 0.0001$). Low hemoglobin (anemia) also significantly increased the odds of infection (OR, 1.73; 95% CI 1.10–2.72, $P = 0.02$). A study of 78 total joint replacements reported that preoperative albumin level was a significant predictor for surgical site infection ($P = 0.01$) [8]. Preoperative and postoperative total lymphocyte count and postoperative albumin were not significant predictors.

Interestingly, the most recent guidelines based on recommendations from the World Health Organization and the Center for Disease Control and Prevention for the prevention of surgical site infection at the time of writing failed to mention preoperative malnutrition issues [15, 16]. A systematic review by Alamanda and Springer [17] on studies that investigated modifiable risk factors for reducing infection recommended albumin or transferrin preoperative testing, as well as advice from a dietitian in the presence of malnutrition. Other methods to detect undernutrition include anthropometric measurements such as calf circumference (<31 cm), arm muscle circumference (<22), and triceps skinfold [4]. However, there are no standard values, and the use of these measurements is not as well supported as the use of serologic laboratory values.

There are also standardized malnutrition screening tools, including the Mini Nutritional Assessment (MNA) that has been shown to be reliable and valid in the geriatric population [18] (Table 2.3). Six questions are answered, and based on the score, 14 other items may then be required to determine nutritional status. Guigoz [18] conducted a review of the sensitivity and specificity of the MNA and concluded this instrument is accurate in identifying nutrition risk. Sensitivity compared with low albumin concentrations ranged from 72% to 100% in eight studies. In addition, receiver operating characteristic curves showed high accuracy of 0.916 for albumin levels <3.5 g/dL.

The subjective global assessment [19] and the Nutritional Risk Screening 2002 (NRS 2002, Table 2.4) [20] are two other commonly used screening tools for malnutrition. Ozkalkanli et al. [21] compared these two instruments in 223 patients scheduled for orthopedic surgery. Sensitivity, specificity, and positive and negative predictive values for the prediction of postoperative complications were calculated. The NRS 2002 had higher sensitivity (69% vs. 50%) and specificity (80% vs. 77%) values and higher OR for the association between malnutrition and occurrence of postoperative complications (4.1 vs. 3.5).

It is important to know all aspects of the dietary status of the patient before surgery including weight loss, change in dietary habits, and loss of appetite. In addition, the psychological status of the patient should be understood including bereavement, loss of a loved one, and home care status. In this regard, the importance of determining the home care that will be provided is paramount. This includes identification of individuals who will provide meals to maintain adequate nutrition, assist with bodily functions, and drive the patient to orthopedic and rehabilitation follow-up visits. The goal is to have the patient remain at home if possible; however, if a postoperative rehabilitation facility is required, the patient's status is closely monitored including diet, hydration, anemia from blood loss, and rehabilitation progress as there may exist quality differences in rehabilitation facilities.

2.2 Effects of Preoperative Obesity and Underweight States

In the USA, the prevalence of obesity (BMI $\geq$ 30 kg/m^2) among adults in 2017–2018 was 42.4%. The rates according to age were 40% in individuals aged 20–39, 44.8% in ages 40–59, and 42.8% in ages ≥60 [22]. Severe obesity (BMI $\geq$ 40 kg/m^2) was present in 9.2% of all adults. In comparison, prevalence rates in 1999–2000 were

Table 2.3 Mini Nutritional Assessment (MNA)[a]

Complete the screening (A–F); if the summed score is <11 points, continue with the remaining questions to derive a malnutrition indicator score		
Question	Responses	Points
A. Has food intake declined over the past 3 months due to loss of appetite, digestive problems, and chewing or swallowing difficulties?	Severe decrease in food intake Moderate decrease in food intake No decrease in food intake	0 1 2
B. Weight loss during the last 3 months	Does not know Between 1 and 3 kg (2.2–6.6 lbs) No weight loss	0 1 2
C. Mobility	Bed or chair bound Able to get out of bed/chair but does not go out Goes out	0 1 2
D. Has suffered psychological stress or acute disease in the past 3 months	Yes No	0 2
E. Neuropsychological problems	Severe dementia or depression Mild dementia No psychological problems	0 1 2
F. Body mass index	<19 19–21 21–23 >23	0 1 2 3
Sum items A–F	*0–7 points: malnourished* *8–11 points: at risk of malnutrition* *12–14 points: normal nutritional status*	
G. Lives independently (not in nursing home or hospital)	No Yes	0 1
H. Takes more than 3 prescription drugs a day	No Yes	1 0
I. Pressure sores or skin ulcers	No Yes	1 0
J. How many full meals does the patient eat daily?	1 meal 2 meals 3 meals	0 1 2
K. Selected consumption markers for protein intake: 1. At least 1 serving of dairy products per day 2. Two or more servings of legumes or eggs per week 3. Meat, fish, or poultry every day	If 0 or 1 yes responses If 2 yes responses If 3 yes responses	0 0.5 1
L. Consumes 2 or more servings of fruit or vegetables per day	No Yes	0 1
M. How much water (water, juice, coffee, tea, milk) is consumed per day	<3 cups 3–5 cups >5 cups	0 0.5 1

(continued)

Table 2.3 (continued)

Complete the screening (A–F); if the summed score is <11 points, continue with the remaining questions to derive a malnutrition indicator score		
Question	Responses	Points
N. Mode of feeding	Unable to eat without assistance Self-fed with some difficulty Self-fed without any problem	0 1 2
O. Self-view of nutritional state	Views self as malnourished Is uncertain of nutritional state Views self as having no nutritional problem	0 1 2
P. In comparison with other people of the same age, how does the patient consider his/her health status?	Not as good Does not know As good Better	0 0.5 1 2
Q. Midarm circumference in cm	<21 21–22 >22	0 0.5 1
R. Calf circumference in cm	<31 ≥31	0 1
Sum items A–F		
Sum items G–R		
Total score	*<17 points = malnourished* *17–23.5 points = at risk of malnutrition* *24–30 points = normal nutritional status*	

[a]From Guigoz et al. [18]

Table 2.4 Nutrition Risk Screening 2002 for patients >70 years of age[a]

Factor	Score
Nutrition score: Weight loss >5% in 3 months or food intake below 50–75% in preceding week	1
Weight loss >5% in 2 months, BMI 18.5–20.5 kg/m^2 and impaired general condition, or food intake 25–60% in preceding week	2
Weight loss >5% in 1 month or >15% in 3 months, BMI <18.5 kg/m^2 and impaired general condition, or food intake 0–25% in preceding week	3
Severity of disease score: Hip fracture, chronic patient with acute complications	1
Major abdominal surgery, stroke, severe pneumonia, hematologic malignancies	2
Head injury, bone marrow transplantation, intensive care patients with Acute Physiology and Chronic Health Evaluation >10	3
Overall score: Total ≥3 = nutritional risk; ≥5 high risk	

[a]From Kondrup et al. [20]

30.5% for obesity and 4.7% for severe obesity. A study from Norway that followed 225,908 individuals for 12 years reported that weight gain increased the risk for TKA in patients <40 years of age [23]. For men, an increase of 5 kg of weight resulted in a 26% increased risk of TKA in those aged 17–20 years at their first screening and a 13% increased risk in those aged 21–40. For women, an increase of 5 kg was associated with a 43% increased risk for TKA in those aged 17–20 years and a 24% increased risk for those aged 21–40.

Many investigations have reported that obesity is associated with increased rates of postoperative infection (Table 2.5) and other major complications following total joint arthroplasty [2, 7, 24–35]. One study [36] found an association between aseptic tibial component loosening and TKA failure and increased BMI. Patients with a BMI ≥35 kg/m^2 had an increased cumulative probability of revision at 15 years compared with those with BMI <35 kg/m^2 (4.27% and 1.23%, respectively; hazard ratio [HR], 2.3; 95% CI 1.3–3.9; $P < 0.01$). Boyer et al. [37] in a registry study of 28,483 TKAs reported no association between BMI and revision for any reason, septic loosening, or aseptic loosening.

D'Apuzzo et al. [25] compared postoperative complication rates between 90,143 morbidly obese (≥40 kg/m^2) patients and 90,442 nonobese (<30 kg/m^2) patients and reported significant increases in infection, anemia, wound dehiscence, genitourinary disease, peripheral vascular disease, respiratory disease, and death in the morbidly obese cohort (OR range 0.7–3.2; $P < 0.05$). In a study of 34,800 TKA patients, Fu et al. [2] found that morbid obesity (BMI ≥40 kg/m^2) significantly increased the odds of postoperative complications (OR, 1.31; $P = 0.005$), wound complications (OR, 1.99; $P = 0.001$), and return to the operating room within 30 days (OR, 1.59; $P = 0.01$). However, this study reported that a multivariable analysis that adjusted for BMI found that preoperative malnutrition (albumin <3.5 g/dL) was a stronger predictor for multiple complications (Table 2.6).

A study of 34,744 patients from the Danish nationwide registry [32] who underwent total joint replacement surgery found that patients with a BMI >35 kg/m^2 ($N = 3295$) had an increased risk of a major cardiovascular event within 30 days (HR, 1.2; 95% CI 0.67–2.1), mortality within 30 days (HR, 2.3; 95% CI 1.08–5.0), cardiovascular mortality within 30 days (HR, 2.4; 95% CI 0.94–6.2), mortality within 1 year (HR, 1.7; 95% CI 1.2–2.4), and cardiovascular mortality within 1 year (HR, 2.2; 95% CI 1.4–3.5). However, the highest risk group in this study was underweight patients ($n = 353$) with a BMI <18.5 kg/m^2 who had an increased risk (compared with patients with a BMI of 25–29 kg/m^2) of a major cardiovascular event within 30 days (HR, 2.0; 95% CI 0.7–5.4), mortality within 30 days (HR, 7.7; 95% CI 3.1–19.0), cardiovascular mortality within 30 days (HR, 4.1; 95% CI 0.9–18.0), mortality within 1 year (HR, 5.7; 95% CI 3.8–8.4), and cardiovascular mortality within 1 year (HR, 2.5; 95% CI 1.09–5.9).

Wallace et al. [34] followed 32,485 TKA patients and reported that increased BMI was associated with an increased risk of pulmonary embolism (PE) or deep venous thrombosis (DVT) and wound infection by 6 months postoperatively. The greatest increase was found in patients with BMI >35 kg/m^2 for PE/DVT (OR, 1.93; 95% CI 1.45–2.57; $P < 0.001$) and for wound infection (OR, 1.39; 95% CI 1.11–1.72;

Table 2.5 Association between obesity/body mass index and total joint arthroplasty infection

Study	Arthroplasty type	Infection type	Cohort (N)	BMI (kg/m²)	OR	95% CI
Kunutsor et al. [30]	TKA and THA	Periprosthetic joint	N/A (29 studies, meta-analysis)	≥30 vs. <30	1.60	1.29–1.99
				≥35 vs. <35	1.53	1.22–1.92
				≥40 vs. <40	3.68	2.25–6.01
Jamsen et al. [28]	TKA and THA	Periprosthetic joint	1105	≤25	(reference)	NA
			2461	25–29	1.24	0.39–3.89
			1635	30–34	2.38	0.78–7.24
			559	35–39	1.49	0.33–6.66
			193	≥40	13.46	4.10–44.17
Everhart et al. [26]	All primary and revision joint arthroplasties	Surgical site	1875	<18.5	1.90	0.26–13.7
				25–29.9	0.60	0.24–1.50
				30–39.9	0.84	0.51–1.41
				40–49.9	1.28	0.61–2.65
				≥50	15.69	5.97–41.21
Jung et al. [29]	TKA	Periprosthetic joint	983	<25	(reference)	NA
			2712	25–30	0.36	0.10–1.26
			2757	30–35	0.86	0.30–2.45
			1570	35–40	1.51	0.53–4.31
			923	>40	1.72	0.56–5.27
George et al. [27]	TKA	Periprosthetic joint	14,989	<25	(reference)	NA
			41,155	25–29.9	0.90	0.61–1.32
			71,709	30–39.9	1.14	0.80–1.62
			23,081	≥40	2.14	1.48–3.10
		Superficial	14,989	<25	(reference)	NA
			41,155	25–29.9	0.85	0.64–1.14
			71,709	30–39.9	1.24	0.95–1.61
			23,081	≥40	2.02	1.53–2.67
Alvi et al. [24]	TKA and THA	Deep incision	6016	<25	(reference)	NA
			13,289	25–30	0.73	0.23–2.27
			11,558	30–35	1.06	0.38–2.97
			6820	35–40	1.40	0.52–3.73
			5184	>40	3.22	1.34–7.22

		Superficial	6016	<25	(reference)	NA
			13,289	25–30	0.76	0.34–1.69
			11,558	30–35	1.37	0.71–2.66
			6820	35–40	1.68	0.83–3.40
			5184	>40	2.29	1.14–4.61
D'Apuzzo et al. [25]	TKA	In-hospital	90,045	≥40	1.3	1.1–1.7
Fu et al. [2]	TKA	Wound complication	34,800	≥40	1.99	1.33–2.98
Wallace et al. [34]	TKA	Wound infection	32,303	18.5–25	(reference)	NA
				25–30	1.41	1.13–1.75
				30–35	1.59	1.26–1.99
				>35	1.93	1.45–2.57
Werner et al. [35]	TKA	Infection	1,681,681	<30	(reference)	NA
				≥50	13.0	12.0–14.2

NA not applicable, *THA* total hip arthroplasty, *TKA* total knee arthroplasty

Table 2.6 Adjusted odds of developing postoperative complications by obesity classification and preoperative malnutrition[a]

Complication	Category	OR	95% CI	P value
Any	Obese III	1.31	1.08–1.58	0.005
	Malnutrition	1.37	1.11–1.68	0.003
Any major	Obese III	1.18	0.95–1.47	NS
	Malnutrition	1.32	1.04–1.68	0.02
Any wound	Obese III	1.99	1.33–2.98	0.001
	Malnutrition	1.78	1.20–2.64	0.005
Cardiac	Obese III	0.96	0.45–1.23	NS
	Malnutrition	2.23	1.21–4.12	0.01
Respiratory	Obese III	0.52	0.29–0.95	0.03
	Malnutrition	3.75	2.46–5.71	<0.001
Return to OR within 30 days	Obese III	1.59	1.11–2.27	0.01
	Malnutrition	1.10	0.71–1.71	NS
Death	Obese III	1.40	0.47–4.21	NS
	Malnutrition	3.17	1.46–6.90	0.004

[a]From Fu et al. [2]
Obese III (≥40 kg/m^2), preoperative malnutrition (albumin <3.5 g/dL), Note, no significant findings for obese class I or II

P = 0.003). This study found no increased risk of mortality within 6 months according to BMI. Tohidi et al. [33] followed a cohort of 9817 TKA patients for 10 years postoperatively and reported that morbidly obese patients (BMI ≥45 kg/m^2) had a 50% higher risk of mortality than nonmorbidly obese patients (risk ratio, 1.50; 95% CI 1.22–1.85).

The effects of super-obesity (BMI ≥ 50 kg/m^2) on postoperative complications were reported by Werner et al. [35] in a cohort of 1,681,681 primary TKA patients. Patients in this category had a higher overall rate of complications within 90 days postoperatively (24.7%) compared with non-obese (3.0%), obese (8.3%), and morbidly obese (13.1%) patients. For infection, ORs for super-obese patients were 13.0 compared with non-obese, 5.3 compared with obese, and 2.5 compared with morbidly obese (*P* < 0.0001 for all comparisons).

Several studies have compared functional outcomes between obese and non-obese patients with differing outcomes [38–45]. Xu et al. [44] followed 126 patients for 10 years postoperatively and compared results from 34 obese (BMI ≥ 30 kg/m^2) to those of 92 non-obese patients. After adjusting for age, gender, and Charlson Comorbidity Index, there was a distinct association between obesity and poorer outcome scores for American Knee Society (AKS) Function Score, Oxford Knee Score, and Physical and Mental Component score of the 36-Item Short-Form Health Survey (SF-36; *P* < 0.01). Liljensoe et al. [42] reported 3- to 5-year outcomes on 197 patients that underwent primary TKA. These authors found that after adjusting for age, gender, primary disease, and surgical approach, a difference in BMI of 1 was associated with an 8% increased risk of a poorer score in the SF-36 Physical Component Score, a 4–12% increased risk of a poorer score for eight of the SF-36 individual domains, and a 3–14% increased risk of a poorer result in AKS overall and function scores.

Yoo et al. [45] found no significant differences in AKS scores between obese patients (BMI ≥ 30 kg/m^2, n = 78) and non-obese patients (n = 114, BMI <25 kg/m^2 and n = 179, BMI 25–29 kg/m^2) 5 years postoperatively. Baker et al. [38] reported no effect of BMI on Oxford Knee Score, EuroQol 5D index, and EuroQol 5D visual analogue scale measures in 13,673 primary TKAs followed a mean of 7 months postoperatively. The authors concluded that patients with high BMIs experienced similar magnitude of improvements in these scores as those with normal BMI (<25 versus > 25 kg/m^2). In a separate report [39], these authors reported similar findings at 3 years postoperatively in Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and SF-36 scores. Patients with a BMI of >35 kg/m^2 did have lower rates of patient satisfaction with pain relief compared to those with a BMI of 18.5–25.0 kg/m^2 (84.6% versus 93.3%, P = 0.01). Collins et al. [40] in a report of 445 primary TKAs followed 9 years postoperatively concluded that obesity had a small adverse effect on outcomes; however, substantial improvements were experienced in mildly and highly obese patients. There were no significant differences in complications, revisions, or implant survival between obese and non-obese patients.

Stevens-Laspely et al. [43] evaluated functional performance after TKA in 140 patients 6 months postoperatively. BMI did not account for variance in postoperative timed up-and-go test, stair-climbing test, 6-minute walk test, or SF-36 scores. This population had a mean BMI of 30.8 ± 5.2 kg/m^2 (range, 21.2–40.0 kg/m^2) and did not include severely obese patients. As of the time of writing, we were unable to find other studies in which objective function was determined according to BMI.

2.3 Effects of Preoperative Vitamin D Deficiency

Vitamin D plays an important role on the regulation of bone health and fracture healing, as well as soft tissue healing and function [46]. It is biologically synthesized using ultraviolet B (UVB) rays from the sun and is acquired from food such as liver, cod liver oil, fatty fish, and egg yolks. There remains debate regarding normal ranges according to the level of serum 25-hydroxyvitamin D_3 (25 OHD) [47]. The Vitamin D Council reported ≤30 ng/mL as deficient, 31–39 ng/mL as insufficient, and 40–80 ng/mL as sufficient [48]. The Endocrine Society reported ≤20 ng/mL as deficient, 21–29 ng/mL as insufficient, and 30–100 ng/mL as sufficient [49]. The Food and Nutrition Board Institute of Medicine reported 0–11 ng/mL as deficient, 12–20 ng/mL as insufficient, and >20 ng/Ml as sufficient [50]. Further complicating the matter was a report by Manson et al. [47] that stated that approximately 97.5% of the population require 20 ng/mL or less, and 50% requires 16 ng/mL or less, to maintain good bone health. It is understandable that a wide range of patients undergoing primary total joint arthroplasty (10–80%) have been identified as vitamin D deficient or insufficient [51].

A meta-analysis of the prevalence of preoperative vitamin D deficiency (hypovitaminosis D) and its association with total joint arthroplasty outcomes was recently conducted by Emara et al. [52]. Eighteen studies had a pooled prevalence for vitamin D insufficiency (20 to <30 ng/mL) of 53.4% and deficiency (<20 ng/mL) of 39.4%. Hypovitaminosis D was associated with higher complications rates ($P < 0.05$). Individual studies have reported that vitamin D deficiency resulted in increased hospital length of stay [53–55], higher perioperative complications rates [55–58], and poorer postoperative functional outcomes [53, 59–62]. Hegde et al. [56] reported that vitamin D deficiency (serum 25D <20 nm/mL) resulted in higher manipulation rates (OR, 1.69; $P < 0.001$), surgical site infection (OR, 1.76; $P = 0.001$), DVT (OR, 1.80; $P < 0.001$), and myocardial infarction (OR, 2.11; $P < 0.001$).

Maniar et al. [61] studied the effect of preoperative vitamin D deficiency and postoperative supplementation on functional outcomes in 120 TKA patients. Of the 120 patients, 64 (53%) were found to be deficient (<30 nm/mL), and the remaining were sufficient before surgery. Preoperatively, the deficient group had significantly worse WOMAC scores (48.3 versus 42.3, $P < 0.05$). Postoperatively, all patients took oral vitamin D supplements (5 μg/day) from the 14th postoperative day for 4 weeks. At 3 months postoperatively, there were no significant differences between the two groups in several patient-reported outcome measures.

Piuzzi et al. [63] studied prevalence and risk factors of preoperative vitamin D deficiency and insufficiency in 226 total joint arthroplasty patients in the North Midwest region of the USA. Vitamin D insufficiency was defined as <30 ng/mL and deficiency as <20 ng/mL. There were 137 patients (60.6%) in the insufficient group and 61 (26.9%) in the deficient group. On multivariate analysis, an American Society of Anesthesiologists (ASA) score ≥3 was an independent risk factor for vitamin D insufficiency (OR, 2.44; $P < 0.001$), while ACA ≥3 (OR, 3.57; $P < 0.001$) and younger age (OR, 0.96; $P = 0.002$) were independent risk factors for deficiency. There was no association in other factors such as BMI, gender, race, joint type, and comorbidities with deficiency or insufficiency. There were significantly quarterly seasonal changes, with the lowest mean levels of vitamin D found in the first quarter of the year (January, February, and March) and the highest found in the fourth quarter. The authors suggested the clinicians pay particular attention in patients with an ASA score ≥3 and surgery performed during the winter season.

In 2020, Arshi et al. [51] estimated that the implementation of widespread preoperative 25 OHD testing and repletion in deficient cases would result in cost savings (for reducing joint infection) of over $1,000,000 per 10,000 cases. The use of selective preoperative screening to detect vitamin D-deficient patients (<20 ng/mL) and the use of repletion with oral supplements to normal levels (>30 ng/mL) in these individuals were projected to result in $1,504,857 (range, $215,084–$4,256,388) in cost savings. The use of vitamin D supplementation preoperatively in all patients (without screening) was projected to result in $1,906,077 (range, $616,304–$4,657,608) in cost savings.

Accordingly, preoperative 25 OHD has become a routine screening test at our center for a number of years and should be assessed well before surgical planning in older adults to allow for optimization if a deficiency is present.

2.4 Indications for Bariatric Surgery Before TKA

It is important to develop a relationship with a nutritional and dietary center to assist patients who require preoperative optimization. There are many options available in this field, and patients are advised of specific programs available on the Internet, through commercial companies, or based in hospitals that may be effective. Frequently, when the surgeon states that surgery must be postponed due to increased complication rates already discussed, the patient and their family become more serious on obesity issues and will adopt a program, thereby delaying surgery for 3–6 months. Simple suggestions are often effective such as avoiding a high-carbohydrate diet including candy and soft drinks, decreasing portion sizes by one-half, use of protein supplements for one portion of meal, and avoiding snacking. An important part of weight loss is to initiate any type of physical activity including water therapy, stationary biking, flexibility, low intensity yoga or pilates, and upper body workouts. This represents a comprehensive program at our center involving the entire team to encourage and assist patients with weight loss to avoid bariatric surgery, which is considered the last resort in the treatment strategy.

It is unfortunate that weight loss strategies are frequently ineffective in morbidly obese patients (BMI ≥ 40 kg/m^2). Bariatric surgery (BS) may be considered when all conservative management programs fail, including lifestyle modification and pharmacotherapy, especially in patients with obesity-related comorbidities such as hypertension and diabetes [64]. The literature is conflicted on the impact of preoperative BS on outcomes and complications after total joint arthroplasty. A recent systematic review of 13 studies encompassing 11,770 patients found no consensus of the effect of previous BS on short-term outcomes of total hip or knee arthroplasty [65]. A prior systematic review of five studies that compared obese patients who had undergone BS to those who had not found no significant difference in outcomes including infection, DVT, readmission, revision surgery, or mortality [66].

A report published after the two systematic reviews just discussed used data from the Nationwide Inpatient Sample in the USA to compare complications between 9803 patients with morbid obesity who underwent BS to 9803 patients with morbid obesity who did not undergo this procedure [67]. The group that did not undergo BS had a significantly higher risk of postoperative complications and longer length of hospital stay (Table 2.7). However, incidences of blood transfusion and anemia were greater in the BS group. The authors believed this could have been secondary to malnutrition due to malabsorption after BS. The results of this study provided a general conclusion that BS may be of benefit for obese patients undergoing total joint arthroplasty but cautioned that not all complications will be reduced.

A study of 25,852 Medicare patients who underwent BS followed by TKA from 2004 to 2016 reported differences in complication rates according to the type of BS (Table 2.8) [68]. When compared with 2,675,575 TKA patients who had not undergone a BS, the BS group as a whole had higher risks of dislocation, implant failure, periprosthetic infection, pneumonia, and wound dehiscence (hazard ratios >2.0). The authors of this study concluded that BS did not normalize post-TKA risks. It is

Table 2.7 Effect of bariatric surgery on complications, length of stay, and costs of TKA[a]

Variable	Morbid obesity No preop BS (%)	Morbid obesity Preop BS (%)	OR (95% CI)	*P* value
Higher morbid obesity, no preop BS				
Pulmonary embolism	0.57	0.19	0.34 (0.20–0.57)	<0.0001
Respiratory complication	0.43	0.19	0.45 (0.26–0.78)	0.003
Death	0.15	0.01	0.07 (0.01–0.50)	0.0005
Length of stay, mean +/- SD	3.31 ± 1.84	3.12 ± 1.21		<0.0001
Cost, mean +/- SD	$18,162 ± 8265	$18,029 ± 8089		0.05
Higher preop BS				
Anemia	21.62	24.28	1.16 (1.09–1.24)	<0.0001
Blood transfusion	9.02	15.65	1.87 (1.71–2.04)	<0.0001

CI confidence interval, *OR* odds ratio
[a]From Wang et al. [67]

important to note that patients undergoing BS are at high risk for remaining nutritional and metabolic abnormalities already discussed that require optimization prior to surgery. Another study of 86,609 Medicare patients who underwent BS and then primary TKA from 1999 to 2012 reported that compared with controls, BS patients had increased risk of revision for any reason at 1 year (HR, 4.3; $P = 0.003$), 2 years (HR, 3.58; $P = 0.004$), and 5 years (HR, 3.37; $P = 0.003$) [69]. Patients who underwent BS were not at increased risk for postoperative infection.

McLawhorn et al. [70] compared complications and risk of revision between matched cohorts of 2636 patients who had BS and 2636 morbidly obese patients who did not before TKA. There were significantly increased odds of any in-hospital complications and 90-day postoperative complications in patients who did not undergo BS (OR, 0.69 and 0.61, respectively; $P < 0.05$). There was no difference between groups for revision. The authors concluded that preoperative discussions of referral for bariatric evaluation are appropriate for morbidly obese patients.

The experience of our center in regard to patients with morbid obesity and the problems in compliance with recommendations is entirely in agreement with a recent study. Springer [71] followed 289 patients who presented with BMI >40 kg/m^2 and were candidates for total hip or knee replacement. The patients were informed weight loss was required before total joint arthroplasty could be performed and were provided with referral information to bariatric practices for weight management. The patients were tracked for 2 years to determine what treatment occurred. One-third had no further contact with the office, 67 patients (23%) went for an appointment with a bariatric group, and just four (3%) had BS. Overall, 56 (19%) underwent total joint arthroplasty; not all lost weight but found another orthopedic surgeon who performed the procedure (BMI range at surgery, 27.5–53.0 kg/m^2). The author acknowledged that current methods failed to provide appropriate resources to patients and the majority do not lose weight.

Table 2.8 Hazard ratios comparing use of various Bariatric procedures and 90-day post-TKA complications in elderly Medicare patients, 2004–2016[a]

Complication	BS (reference: none)	HR (95% CI)	*P* value
Death	Gastric bypass	1.90 (1.00–3.64)	0.05
	Procedure NA	1.29 (1.00–1.65)	0.04
	Sleeve gastrectomy	1.18 (0.44–3.16)	NS
	Band gastroplasty	0.61 (0.20–1.88)	NS
Implant failure	Sleeve gastrectomy	2.54 (1.45–4.46)	0.001
	Procedure NA	1.71 (1.47–1.99)	<0.001
	Gastric bypass	1.57 (0.88–2.81)	NS
	Band gastroplasty	1.24 (0.70–2.18)	NS
Periprosthetic infection	Band gastroplasty	2.32 (1.54–3.50)	<0.001
	Procedure NA	1.96 (1.69–2.26)	<0.001
	Sleeve gastrectomy	1.76 (0.92–3.37)	NS
	Gastric bypass	0.82 (0.39–1.72)	NS
Pneumonia	Gastric bypass	2.08 (1.31–3.29)	0.002
	Band gastroplasty	1.44 (0.87–2.37)	NS
	Procedure NA	1.35 (1.14–1.59)	<0.001
	Sleeve gastrectomy	0.94 (0.42–2.09)	NS
Readmission	Procedure NA	1.44 (1.38–1.51)	<0.001
	Sleeve gastrectomy	1.37 (1.12–1.68)	0.002
	Band gastroplasty	1.34 (1.16–1.55)	<0.001
	Gastric bypass	1.24 (1.06–1.46)	0.007
Renal failure	Sleeve gastrectomy	1.63 (1.06–2.51)	0.03
	Procedure NA	1.47 (1.31–1.64)	<0.001
	Band gastroplasty	1.39 (0.96–2.01)	NS
	Gastric bypass	1.13 (0.72–1.77)	NS
Revision	Band gastroplasty	1.90 (1.22–2.94)	0.004
	Procedure NA	1.68 (1.44–1.96)	<0.001
	Sleeve gastrectomy	1.45 (0.73–2.89)	NS
	Gastric bypass	0.79 (0.38–1.66)	NS
Wound dehiscence	Band gastroplasty	2.54 (1.59–4.05)	<0.001
	Procedure NA	2.11 (1.78–2.52)	<0.001
	Sleeve gastrectomy	1.98 (0.95–4.13)	NS
	Gastric bypass	1.58 (0.82–3.04)s	NS

CI confidence interval, *HR* hazard ratio, *NA* not available, *NS* not significant
[a]From Meller et al. [68]

Recommendation was made for collaboration to occur between the American Association of Hip and Knee Surgeons and the American Society of Metabolic and Bariatric Surgeons in order to define optimal care and develop national programs.

2.5 Strategies to Improve Nutritional Status

The importance of adequate albumin levels has been discussed previously. Patients with low albumin are likely to also lack other important vitamins that are essential for wound healing and proper immune function. All of our patients undergo preoperative protein testing to ensure either adequate levels exist or if supplementation is required. We recommend adding proteins and amino acids to patients' diets 4 weeks preoperatively and 8 weeks postoperatively. Many good liquid preparations are available online and at major retail or pharmacy stores that are high in protein but low in carbohydrates and calories. Patients who are lactose intolerant are encouraged to use plant-based products. Yogurt or probiotic products are recommended 4 weeks before surgery to help prevent gastrointestinal problems postoperatively. A daily multivitamin including vitamins D and C is recommended 8 weeks before and after surgery. Vitamin D levels are tested on all patients and deficiencies expected in patients not routinely exposed to sunlight. Calcium supplementation is recommended for patients with decreased bone density as determined with a DEXA scan. Iron deficiency anemia should be excluded with appropriate hemoglobin and hematocrit testing, and if present, referral is required for determination of the causes including necessity for appropriate colon screening tests.

Few studies have determined the effect of preoperative nutritional supplementation on outcomes in TKA patients [72]. In one study [73], 19 patients who received essential amino acid supplementation (1 week before and 6 weeks after TKA) had reduced muscle volume atrophy 6 weeks postoperatively compared with 20 patients who received a placebo. Quadriceps atrophy in the involved side was significantly greater in the placebo group compared with the supplementation group (−13.4% ± 1.9% and − 8.5% ± 2.5%, $P < 0.05$), as was hamstrings atrophy (−12.2% ± 1.4% and − 7.4% ± 2.0%, $P < 0.05$). However, there was no significant difference in isometric muscle strength or functional measures such as the timed up-and-go and stair-climb tests between groups. In a double-blind randomized controlled trial (RCT) [74], 30 patients received essential amino acid supplementation and 30 a placebo 1 week before to 2 weeks after TKA. Four weeks postoperatively, the supplementation group demonstrated superior relative changes in rectus femoris muscle area and quadriceps muscle diameter ($P < 0.05$) and better visual analogue scores for knee pain ($P < 0.05$). There was no significant difference between groups for quadriceps isometric strength or 6-m timed walk.

Schroer et al. [1] studied the effect of a high-protein, anti-inflammatory diet administered in patients with malnutrition on post-TKA length of stay, readmission rates, and costs. All TKA patients attended a mandatory preoperative education class and received instruction regarding the benefits of the diet (Table 2.9), which was to be followed for 1 month before surgery. Patients with a preoperative serum albumin levels ≤3.4 g/l were called and specifically encouraged to follow the diet. After surgery, these patients were seen by an inpatient dietitian during their hospital stay who reinforced maintenance of the diet postoperatively. There was a significant difference in the length of hospital stay, readmissions, and mean charges for

Table 2.9 Anti-inflammatory, high-protein diet for malnourished patients[a]

Anti-inflammatory diet goals
Limit or omit red meat, sugar, saturated fats, and simple carbohydrates
Increase fish, nuts, seeds, fruits, vegetables, and whole grains
Increase protein to 100 g per day unless medically contraindicated (i.e., renal disease)
Liquid protein supplements only when goals not met through food

[a]From Schroer et al. [1]

primary hospitalization, readmissions, and 90 days of care in the malnourished patients who received the nutritional intervention compared with those who did not ($P < 0.05$). The authors concluded that their program was effective and recommendable but remarked that there is no consensus regarding the length of time patients should optimize their nutrition before TKA. One limitation of this study was that patients did not receive a second albumin test after participation in the diet program and were not tracked postoperatively to determine if the diet was maintained.

Weight loss programs such as Weight Watchers and physician or dietitian-based exercise and diet treatment plans should be recommended in obese patients as already discussed. However, few studies have evaluated their overall efficacy in TKA patients, and more well-designed research is required. As discussed, the effects of preoperative BS are conflicting with regard to postoperative outcomes and complications. Caution is warranted and further research required to determine the optimal TKA candidates for these procedures.

2.6 Patient Indications and Selection Criteria

Criteria for TKA include failure of all nonoperative treatment measures (physical therapy, medications, weight control, injection therapeutic options, lifestyle modifications) and other surgical procedures to alleviate pain with daily activities. Bi- and tricompartmental severe loss of radiographic joint space and articular cartilage are indications, whereas single compartmental severe arthritis may be treated with a unicompartmental knee arthroplasty.

Women over 50 years of age or with any family history of low bone density or bone mass require a DEXA scan to rule out osteoporosis. There should be no gum infection or major dental problems. Any urinary risk factors such as recurrent infection or difficulty voiding require treatment before surgery. Iron deficiency anemia must be excluded. Diabetics is an added risk factor for surgery, and it is highly important that the patient's A1C test be normal (<5.7%) and not elevated. Patients with peripheral vascular disease risk factors should undergo assessment of current symptoms, history of vasculopathy, assessment of pulses, and ankle brachial pressure test [75, 76]. An index of <0.9 requires referral for vascular assessment before TKA.

Smoking increases the risk of complications and mortality after TKA [75, 77–80]. In a study of 56,212 TKAs, Matharu et al. [79] found that smokers had increased risk of lower respiratory tract infection (4.2% versus 2.7% non-smoker), increased usage of analgesics (7.4% versus 5.2%), and higher 1-year mortality rates (1.1% versus 0.9%) compared with non-smokers. Bedard et al. [77] conducted a meta-analysis of 14 studies encompassing 227,289 primary total hip and joint arthroplasty patients to determine the relationship between tobacco use and risk of postoperative complications. Tobacco use was associated with increased risk of wound complications (OR, 1.78; 95% CI 1.32–2.39) and periprosthetic joint infection (OR, 2.02; 95% CI 1.47–2.77). There was a significantly increased risk of wound complication and periprosthetic joint infection for current tobacco users compared with former users, suggesting that smoking cessation preoperatively could have a positive impact. Smoking should be stopped at least 1 month before surgery [81, 82].

Appropriateness criteria, a method that combines available scientific evidence with expert opinion, for TKA have been described by various authors (Table 2.10) [83–87]. The RAND approach, developed in the 1980s [88], was used in two studies that subsequently determined that 31% [85] to 49% [83] of TKA cases were "inappropriate" according to the RAND criteria. One of these investigations reported no significant difference in clinical outcome measures between patients classified as inappropriate and those classified as appropriate or inconclusive at 1 and 2 years postoperatively [85]. The American Academy of Orthopaedic Surgeons published appropriateness criteria for the management of knee osteoarthritis in 2016 that addressed the use of TKA, unicompartmental arthroplasty, and realignment osteotomy [89]. Katz et al. [90] described the limitations of appropriateness criteria and recommended constant reevaluation and updating of these systems. In addition, several studies have published recommended guidelines for TKA. Gademan et al. [91]

Table 2.10 Appropriateness criteria for TKA

Variable	AAOS system[a]	Modified Escobar (RAND) system[b]
Function: limiting pain	1 = moderate to long distance (walking >1/4 mile) 2 = short distance (walking 2 city blocks, length of a shopping mall) 3 = pain at rest or night	1 = slight; combined WOMAC pain and function score of 0–11 2 = moderate; combined WOMAC pain and function score of 12–22 3 = intense; combined WOMAC pain and function score of 23–33 4 = severe; combined WOMAC pain and function score $\geq$ 34
Range of motion	1 = full 2 = >5° flexion contracture and/or flexion <110° 3 = >10° flexion contracture and/or flexion <90°	1 = preserved mobility and stability (extension loss <5° and normal or mild medial or lateral gapping in 20° of flexion) 2 = extension loss ≥5° or moderate or severe medial or lateral gapping in 20° of flexion
Functional instability	1 = none 2 = functional instability	None
Pattern of arthritic involvement	1 = predominately 1 compartment 2 = >1 compartment	1 = unicompartmental tibiofemoral osteoarthritis 2 = bicompartmental osteoarthritis 3 = tricompartmental osteoarthritis
Imaging	1 = mild to moderate 2 = severe	1 = Kellgren-Lawrence grade $\leq$ 2 2 = Kellgren-Lawrence grade 3 3 = Kellgren-Lawrence grade 4
Limb alignment	1 = normal 2 = varus or valgus	None
Mechanical symptoms	1 = no 2 = yes	None
Age	1 = young 2 = middle-aged 3 = elderly	1 = <55 2 = 55–65 3 = >65

[a]From the American Academy of Orthopaedic Surgeons [92]
[b]From Riddle et al. [87]

systematically reviewed the literature and found that the quality of evidence for TKA guidelines was generally low and specific cut-off values or ranges for specific criteria (such as pain and function) were frequently not provided. Future work in this area should consider the constant evolution of TKA procedures, changes in demographic features of patient candidates, influence of reimbursement requirements, and the need to include cut-off values using validated symptom and function rating systems.

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