Sarcopenia is a loss of skeletal muscle mass in the elderly that is an independent risk factor for falls, disability, postoperative complications, and mortality. Although its cause is not completely understood, sarcopenia generally results from a complex bone–muscle interaction in the setting of chronic disease and aging. Sarcopenia cannot be diagnosed by muscle mass alone. Diagnosis requires 2 of the following 3 criteria: low skeletal muscle mass, inadequate muscle strength, and inadequate physical performance. Forty-four percent of elderly patients undergoing orthopedic surgery and 24% of all patients 65 to 70 years old are sarcopenic. Although dual-energy x-ray absorptiometry and bioelectrical impedance analysis may be used to measure sarcopenia and are relatively inexpensive and accessible, they are generally considered less specific for sarcopenia compared with computed tomography and magnetic resonance imaging. Sarcopenia has been shown to predict poor outcomes within the medical and surgical populations and has been directly correlated with increases in taxpayer costs. Strengthening therapy and nutritional supplementation have become the mainstays of sarcopenia treatment. Specifically, the American Medical Directors Association has released guidelines for nutritional supplementation. Although sarcopenia frequently occurs with osteoporosis, it is an independent predictor of fragility fractures. Initiatives to diagnose, treat, and prevent sarcopenia in orthopedic patients are needed. Further investigation must also explore sarcopenia as a predictor of surgical outcomes in orthopedic patients. [Orthopedics. 2016; 39(2):e295-e300.]
and increase functional outcomes after unilateral hip arthroplasty. However, more work is required to understand the effects of sarcopenia on preoperative risk stratification and postoperative morbidity. This article provides an in-depth review of the underlying bone–muscle interaction of sarcopenia as it relates to surgical outcomes.

**Sarcopenia**

**Definition and Diagnosis**

The most widely accepted definition of sarcopenia is that of the European Working Group on Sarcopenia in Older People (EWGSOP), constructed in 2009 and 2010. The group concluded that the diagnosis of sarcopenia requires 2 of 3 criteria: low skeletal muscle mass, inadequate muscle strength, and inadequate physical performance (Figure 1A).

**Skeletal Muscle Mass**

Muscle mass may be measured with either skeletal muscle index or cross-sectional area, although cross-sectional area is generally considered more specific. Skeletal muscle index may be measured with either dual-energy x-ray absorptiometry (DEXA) or bioelectrical impedance analysis, 2 methods that rely on indirect measures as a surrogate for soft tissue content. Specifically, DEXA relies on absorption of soft tissue radiographs to provide an estimate of appendicular muscle mass, whereas bioelectrical impedance analysis approximates total body water and muscle composition by measuring the body’s resistance to the flow of electric current. Although DEXA and bioelectrical impedance analysis are relatively inexpensive and accessible, they are generally considered less specific for sarcopenia compared with computed tomography (CT) and magnetic resonance imaging (MRI) and have different cutoff points, depending on the method used.

Regardless of which modality is used, class 1 sarcopenia is defined as between 1 and 2 SDs below the mean value for a standardized age group (18–40 years old), and class 2 sarcopenia is defined as 2 or more SDs below the mean value for the standardized group. Alternatively, Schutz et al proposed that sarcopenia be defined as the lower half of all values for the fat-free mass index divided by height squared for a reference population.

Several techniques for measuring cross-sectional area with CT or MRI have been described, and unfortunately, no consensus is available for a single method. With 1 technique, the cross-sectional area of the quadriceps is divided by body weight, and sarcopenia is defined as 1 SD below the mean for the reference population. Another technique uses axial CT and MRI data from the psoas muscle measured at L3 or L4 to assess for sarcopenia (Figure 2). Some investigators prefer to use the lowest tertile or quartile of total psoas area for their study group, whereas others use the density of the psoas muscle, as measured in Hounsfield units, as a surrogate for muscle and fat composition.

**Muscle Strength**

The most common method for measuring muscle strength is with a grip strength dynamometer. Patients are considered weak if they cannot exert an appropriate grip force on the hand-held device. The 2 most commonly used systems are the Lauretani system, in which the cutoff value is determined by sex (men, 30 kg; women, 20 kg), and the system proposed by Fried et al, in which body mass index is used to set a cutoff value.

**Physical Performance**

Although strength testing generally focuses on the upper extremities, physi-
cal performance testing for sarcopenia primarily involves the lower extremities. The short physical performance battery and gait speed are the most common assessments.\(^27,28\) The short physical performance battery consists of gait speed, a balance test, and a chair stand test, with each category given up to 4 points (Table 1). A score of 8 total points or less qualifies as inadequate physical performance. Similarly, gait speed alone may be used to assess physical performance, with a cutoff value of less than 0.8 m/s. The EWGSOP algorithm (Figure 1B) recommends assessment of gait speed first, with further testing dictated by gait speed results. Measurement of muscle mass should be performed in patients with gait speed of less than 0.8 m/s, and grip strength testing should be performed in those with gait speed of greater than 0.8 m/s.

**Pathophysiology of Bone–Muscle Interaction**

Although it is well known that muscle exerts force on bone that facilitates growth and remodeling via Wolff’s law, a growing body of literature has investigated the endocrine activity of muscle, collectively known as the secretome.\(^29\) For example, muscle-derived hormones, such as interleukin 6, interleukin 8, interleukin 15, and fibroblast growth factor 21, are released during exercise. These may promote anabolism within bone and stimulate lypolysis.\(^15\) Age-related degeneration selectively affects fast-twitch, type 2 muscle fibers, but its potentially deleterious effect on the ability of muscle to function as an endocrine organ is not well understood.\(^30\)

Because aging has metabolic effects on both bone and muscle, osteoporosis is often associated with sarcopenia.\(^31\) For example, age-related decreases in androgenic sex steroids reduce both bone mineral density and muscle mass.\(^32\) Similarly, age-related changes in corticosteroid and vitamin D levels play a large role in both osteoporosis and sarcopenia.\(^33\) Finally, prolonged background inflammation in the setting of muscle wasting has similar effects on both bone and muscle metabolism through the generation of inhibitory hormones, such as tumor necrosis factor alpha, interleukin 1, interleukin 6, activin A, and myostatin, and these changes not only increase osteoclast generation but also induce myoblast death.\(^34\)

In addition to hormones that regulate both bone and muscle, there are hormones produced by muscle tissue that regulate the skeletal system both during normal growth and during healing. These are known collectively as myokines. For example, in vitro studies have shown that mechanically loading myocytes leads to the production of several anabolic factors, including vascular endothelial growth factor and insulin-like growth factor 1, which are necessary for bone growth, especially during development.\(^35\) Moreover, when the endocrine activity of muscle is disrupted by injecting botulinum toxin into murine quadriceps, bony callus formation is dramatically disrupted after femoral fracture.\(^36\)

Additionally, fracture healing is enhanced by muscle endocrine activity. Studies have shown that fracture healing occurs faster with intact muscle and that nonunion rates of tibial fractures in the setting of compartment syndrome are nearly 3 times greater than those of fractures without associated compartment syndrome.\(^37,38\) At the molecular level, insulin-like growth factor 1 is released from muscle near the injured periosteum and promotes bone formation through os-

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**Table 1**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Test Cutoff</th>
<th>Points Awarded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balance</td>
<td>Side-by-side stand &gt;10 s</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Semi-tandem stand &gt;10 s</td>
<td>1</td>
</tr>
<tr>
<td>Tandem stand</td>
<td>3-10 s</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>&gt;10 s</td>
<td>2</td>
</tr>
<tr>
<td>Gait speed</td>
<td>Walk 4 m at normal pace</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;8.7 s</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>6.2-8.7 s</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>4.82-6.2 s</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>&lt;4.82 s</td>
<td>4</td>
</tr>
<tr>
<td>Chair stand</td>
<td>Stand upright from chair 5 times</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;16.7 s</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>13.7-16.7 s</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>11.2-13.7 s</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>&lt;11.2 s</td>
<td>4</td>
</tr>
</tbody>
</table>

*Data from Guralnik et al.\(^28\)
teoblast activation.\textsuperscript{30} Osteoblasts are also formed from stem cells within muscle in response to tumor necrosis factor alpha, which is released from bone during fracture.\textsuperscript{40}

**Effects of Sarcopenia on Surgical Outcomes**

Sarcopenia has been extensively studied in general surgery and is an independent predictor of all-cause mortality in the elderly population.\textsuperscript{41} Lieffers et al\textsuperscript{42} showed that sarcopenia was an independent predictor of both postoperative infection and the need for inpatient rehabilitation in patients undergoing resection for colon cancer (odds ratio, 4.6 and 3.1, respectively). Likewise, for patients with pancreatic adenocarcinoma, sarcopenia conferred a 63\% increased risk of death at 3 years.\textsuperscript{43} For patients undergoing liver transplant, sarcopenia tripled mortality rates at 3 years.\textsuperscript{10} Sarcopenia also directly affects the health care system. In a study of patients undergoing resection for liver metastasis, Peng et al\textsuperscript{44} showed that sarcopenia was associated with longer hospital stay and longer stay in the intensive care unit. Similarly, Sheetz et al\textsuperscript{45} found that sarcopenia independently increased taxpayer costs by $6,989.17/1000 mm\textsuperscript{2} lean psoas area, and this number increased to $26,988.41 in the presence of a postoperative complication. Finally, identifying patients with sarcopenia preoperatively allows the use of conditioning programs for transplant patients that reduce hospital length of stay.\textsuperscript{56}

**Sarcopenia in Orthopedic Surgery**

Sarcopenia occurs in up to 44\% of patients undergoing orthopedic surgery.\textsuperscript{11} In addition to its association with decreased bone mineral density, sarcopenia also appears to be an independent risk factor for fragility fractures in people with or without osteoporosis, leading to a condition known as sarco-osteoporosis.\textsuperscript{47} Further, sarcopenia in the setting of osteoporosis may further exacerbate the risk of fragility fractures, especially considering the added risk of falls in sarcopenic patients.\textsuperscript{9} According to Hida et al,\textsuperscript{48} in a large sample of older women, those who had vertebral compression fractures were twice as likely to have underlying sarcopenia.

A small number of studies also have examined the relevance of frailty in orthopedic surgery. There is no single definition of frailty, but Fried et al\textsuperscript{59} first proposed a set of diagnostic criteria that included weight loss, exhaustion, slow gait speed, weak grip strength, and low physical activity. In essence, frailty can be viewed as a loss of physiologic reserve that combines sarcopenia and exhaustion.\textsuperscript{50} Recent studies showed a high degree of association between frailty and low back pain.\textsuperscript{51} Finally, in a recent study of 481 patients who were treated for low-energy femoral neck fractures, Patel et al\textsuperscript{53} showed that a higher modified frailty index was associated with nearly 4 times the mortality risk at 1 year and 2 years postoperatively.

**TREATMENT**

Although the clinical significance of sarcopenia in orthopedics has not been fully investigated, several studies have examined the effect of treating muscle atrophy on operative outcomes.\textsuperscript{13} Although these studies largely diagnosed atrophy on the basis of patient appearance vs the use of formalized sarcopenia measurements, they are nevertheless useful for understanding the benefit of muscle hypertrophy. For example, in patients undergoing hip arthroplasty, Hauer et al\textsuperscript{55} found that intensive inpatient rehabilitation significantly improved functional performance, although these benefits lasted only while the patient was undergoing resistance training. Similarly, Suetta et al\textsuperscript{13} showed that inpatient rehabilitation in patients undergoing hip arthroplasty led to decreased hospital length of stay.

In recent years, growing attention has been paid to the idea of preoperative rehabilitation, or “prehab.” Some studies showed shorter length of stay in patients receiving prehab, but the results of other studies were less promising, showing only that prehab reduced the number of postoperative rehabilitation sessions.\textsuperscript{54} No studies have used sarcopenia to stratify patients who are suitable for prehab.

In addition, the American Medical Directors Association has released evidence-based nutritional guidelines for patients with sarcopenia (Table 2). Although the effects of muscle retention with supplemental protein ingestion are currently debated, older adults should generally consume approximately 1.2 g/kg/d of

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**Table 2**

<table>
<thead>
<tr>
<th>Supplement</th>
<th>Dosage</th>
</tr>
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<tbody>
<tr>
<td>Protein (whey)</td>
<td>1.2 g/kg/d</td>
</tr>
<tr>
<td>Leucine</td>
<td>3 g/d</td>
</tr>
<tr>
<td>Beta-hydroxy butyrate</td>
<td>2 g/d</td>
</tr>
<tr>
<td>Creatine</td>
<td>0.03-0.5 g/kg before and after resistance training</td>
</tr>
<tr>
<td>Vitamin D</td>
<td>800-1000 IU/d</td>
</tr>
<tr>
<td>Long-chain omega 3 polyunsaturated fatty acids</td>
<td>1.86 g eicosapentaenoic acid/d</td>
</tr>
<tr>
<td></td>
<td>1.50 g docosahexaenoic acid/d</td>
</tr>
</tbody>
</table>

*Data from Bauer et al,\textsuperscript{55} Pennings et al,\textsuperscript{56} Flakoll et al,\textsuperscript{57} Candow and Chilibeck,\textsuperscript{58} Sohl et al,\textsuperscript{59} and Smith et al.\textsuperscript{60}
protein. Ideally, this protein comes in Leucine (3 g/d) and beta-hydroxy butyrate (2 g/d) should also be supplemented to slow the rate of muscle loss.

To combat muscle fatigue associated with sarcopenia, creatine also may be supplemented (0.03-0.5 g/kg before and after resistance training) at appropriate times. As discussed earlier, vitamin D is essential to normal skeletal muscle function and should be supplemented at 800 IU/d. Finally, supplementation with long-chain omega 3 polyunsaturated fatty acids is also recommended because these fatty acids increase anabolic signaling molecules within skeletal muscle via phosphorylation.

**Future Research**

Although several studies in the general surgical literature have highlighted the effects of sarcopenia on surgical outcomes and mortality, little is known about the effects of sarcopenia on outcomes after orthopedic and spinal interventions. Additional research is needed on the diagnosis, treatment, and prevention of sarcopenia to optimize patient outcomes after orthopedic trauma and surgery.

**Conclusion**

The use of sarcopenia as an independent prognostic factor for surgery has increased over the past decade. Sarcopenia has been shown to reliably predict postoperative morbidity and mortality, and it is also an independent risk factor for all-cause mortality in the elderly population. Many basic science studies have investigated the importance of healthy muscle in local regulation of healing bone, a topic particularly relevant for orthopedic surgeons. Although sarcopenia affects as many as for 44% of patients undergoing orthopedic surgery, it has received little attention in the orthopedic literature. Although sarcopenia frequently occurs with osteoporosis, it is an independent phenomenon that may compound the risk of fragility fractures, especially given its link to fall risk in the geriatric population. Future studies are needed to focus on examining sarcopenia as a factor to target patients who are suitable for pre- and postoperative rehabilitation and other interventions, such as diet therapy.

**References**

27. Working Group on Functional Outcome Measures for Clinical Trials. Functional out- comes for clinical trials in frail older persons;


