Total Knee Arthroplasty: Muscle Impairments, Functional Limitations, and Recommended Rehabilitation Approaches

Total knee arthroplasty (TKA) is a commonly performed surgical procedure designed to alleviate knee pain and improve function in individuals with knee osteoarthritis (OA) or rheumatoid arthritis. More than 450,000 TKAs are performed each year in the United States and this number is expected to nearly double by 2020.\textsuperscript{2,69} Despite the high incidence of knee replacement and the availability of postoperative rehabilitative approaches, the resultant muscle impairments are not well defined and are an understudied area of postoperative care.\textsuperscript{1} Of particular interest to rehabilitation professionals is the acute profound postoperative deficit in quadriceps muscle strength\textsuperscript{5,42,52,55,67,70,79,85} (TABLE 1) that fails to completely resolve even years after surgery\textsuperscript{5,29,72,85} (TABLE 2). Hamstring strength deficits have also been reported after TKA surgery\textsuperscript{5,29,42,51,72}; however, the focus on the quadriceps is due to the association of the quadriceps to normal functional activities such as walking and stair climbing.\textsuperscript{5,29,42} Therefore, quadriceps weakness will be the focus of this clinical commentary.

While the reason for quadriceps weakness is not well understood in this patient population, it has been suggested that a combination of muscle atrophy and neuromuscular activation deficits contribute to residual strength impairments.\textsuperscript{54} Failure to adequately address the chronic muscle impairments is potentially limiting the long-term functional gains that may be possible following TKA.

Despite the ubiquitous muscle impairments following TKA, long-term functional outcomes are depicted by both favorable and nonfavorable results. In general, self-report functional questionnaires, like the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and Medical Outcome Study 36-Item Short Form Health Survey (SF-36), show large improvements following TKA.\textsuperscript{21,26,33,35,43,45,51,64} Despite quite dramatic improvements in pain and perceived function, people who have had TKA for advanced knee arthritis have lower scores compared to individuals without knee problems.\textsuperscript{18,59} In contrast to self-reported outcomes, functional performance measures, such as a timed
stair-climbing or walking test, depict only modest improvements following TKA,\textsuperscript{56,81} and substantial residual deficits persist when compared to age- and sex-matched healthy comparison groups. These functional performance findings are consistent in those with chronic quadriceps muscle weakness.\textsuperscript{59,80,85} At times, the deficits in functional performance are quite pronounced. For example, approximately three quarters of patients with a knee replacement report difficulty negotiating stairs\textsuperscript{59} and the average stair-climbing speed is only half as fast compared to healthy counterparts.\textsuperscript{85} Furthermore, following a peak in functional recovery 2 to 3 years after TKA, there is an accelerated decline in function relative to typical age-related decrements.\textsuperscript{66} Physical therapy countermeasures seem ideally suited to mitigate the muscle impairments and functional limitations following TKA. Recent descriptions of postoperative rehabilitation programs with intensive exercise following TKA have reported greater restoration of quadriceps strength, improved functional ability, and an earlier return to activity compared to historical TKA outcomes.\textsuperscript{52,56,62,72}

The purpose of this clinical commentary is 4-fold: (1) to describe the quadriceps strength impairments related to TKA and the associated muscle activation deficits and muscle atrophy; (2) to explore how these impairments contribute to functional limitations; (3) to describe how the current concepts in TKA rehabilitation are attempting to address these impairments; and (4) to outline recommendations and clinical guidelines for rehabilitation based on the best available evidence and therapeutic exercise principles.

TABLE 1

<table>
<thead>
<tr>
<th>Reference</th>
<th>Mean Age</th>
<th>Time</th>
<th>Test Mode</th>
<th>Involved (Nm)</th>
<th>Uninvolved (Nm)</th>
<th>Difference (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berman\textsuperscript{5} (n = 68)</td>
<td>63</td>
<td>Preoperative</td>
<td>Isokinetic 60°/s</td>
<td>35.5</td>
<td>59.9</td>
<td>41</td>
</tr>
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<td>3-6 mo postoperative</td>
<td>Isokinetic 60°/s</td>
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<td>67.0</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Lorentzen\textsuperscript{42} (n = 60)</td>
<td>74</td>
<td>Preoperative</td>
<td>Isokinetic 30°/s</td>
<td>57.0</td>
<td>67.0</td>
<td>15</td>
</tr>
<tr>
<td>Lorentzen\textsuperscript{42} (n = 60)</td>
<td>3 mo postoperative</td>
<td>Isokinetic 30°/s</td>
<td>55.0</td>
<td>78.0</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Lorentzen\textsuperscript{42} (n = 60)</td>
<td>6 mo postoperative</td>
<td>Isokinetic 120°/s</td>
<td>67.0</td>
<td>79.0</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Rodgers\textsuperscript{52} (n = 20)</td>
<td>68</td>
<td>Preoperative</td>
<td>Isokinetic 60°/s</td>
<td>74.6</td>
<td>102.4</td>
<td>27</td>
</tr>
<tr>
<td>Rodgers\textsuperscript{52} (n = 20)</td>
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<td>Isokinetic 60°/s</td>
<td>74.6</td>
<td>102.4</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Rodgers\textsuperscript{52} (n = 20)</td>
<td>3 mo postoperative</td>
<td>Isokinetic 60°/s</td>
<td>74.6</td>
<td>102.4</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Rodgers\textsuperscript{52} (n = 20)</td>
<td>6 mo postoperative</td>
<td>Isokinetic 60°/s</td>
<td>74.6</td>
<td>102.4</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Lorentzen\textsuperscript{42} (n = 60)</td>
<td>74</td>
<td>Preoperative</td>
<td>Isometric 75°</td>
<td>66.0</td>
<td>87.0</td>
<td>24</td>
</tr>
<tr>
<td>Rodgers\textsuperscript{52} (n = 20)</td>
<td>64</td>
<td>Preoperative</td>
<td>Isometric 75°</td>
<td>183.7</td>
<td>225.6</td>
<td>19</td>
</tr>
<tr>
<td>Mizner\textsuperscript{52} (n = 40)</td>
<td>64</td>
<td>Preoperative</td>
<td>Isometric 75°</td>
<td>183.7</td>
<td>225.6</td>
<td>19</td>
</tr>
<tr>
<td>Mizner\textsuperscript{52} (n = 40)</td>
<td>1 mo postoperative</td>
<td>Isometric 75°</td>
<td>183.7</td>
<td>225.6</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Mizner\textsuperscript{52} (n = 40)</td>
<td>2 mo postoperative</td>
<td>Isometric 75°</td>
<td>183.7</td>
<td>225.6</td>
<td>19</td>
<td></td>
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<tr>
<td>Mizner\textsuperscript{52} (n = 40)</td>
<td>3 mo postoperative</td>
<td>Isometric 75°</td>
<td>183.7</td>
<td>225.6</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Mizner\textsuperscript{52} (n = 40)</td>
<td>6 mo postoperative</td>
<td>Isometric 75°</td>
<td>183.7</td>
<td>225.6</td>
<td>19</td>
<td></td>
</tr>
</tbody>
</table>

* Percent difference calculated: [(uninvolved – TKA)/uninvolved] × 100.

Quadriceps weakness has been implicated in the development and progression of knee OA\textsuperscript{56,74} and is related to a decline in physical function.\textsuperscript{15,20,27,32,73} People with knee OA-induced quadriceps weakness consistently exhibit about a 20% strength deficit compared to healthy age- and sex-matched cohorts.\textsuperscript{73} Strength deficits are ubiquitous in people with advanced knee OA who are considering a TKA. Muscle strength assessments in patients with TKA are performed with isometric or slow isokinetic testing speeds. A compilation of these quadriceps strength results before and after short- and long-term follow-up TKA is provided in TABLES 1 and 2. The most common surgical approach during a TKA procedure involves an incision through the extensor mechanism. This surgical approach apparently compounds preoperative strength deficits as patients produce less than half of their preoperative torque values at 1 month after TKA.\textsuperscript{52,54,57,79} While quadriceps strength increases steadily thereafter, significant changes in strength start tapering off 6 to 12 months following surgery (TABLES 1 and 2). Hence, while isometric quadriceps strength improves 10% to 20% from preoperative levels following
TKA (85-95 Nm), strength rarely ever reaches the value of age-matched healthy individuals (105-137 Nm) or the potential isometric or isokinetic strength levels of the nonoperative knee extensor muscles (87-232 Nm). At times, the amount of residual weakness in individuals following TKA is substantial in that a general strength deficit of 20% or more is common. Some caution must be exerted when interpreting results that use the uninjured limb as a comparator. Approximately 40% of patients with unilateral TKA progress to a TKA in their nonoperative lower extremity by 10 years; hence, the uninjured knee should probably not be considered a typically healthy or unimpaired joint. Consequently, these estimates of weakness are conservative.

Table 2: Quadriceps Strength Deficits From 6 Months to 13 Years Following Total Knee Arthroplasty: Comparison to the Uninvolved Side or an Age-Matched Healthy Group*

<table>
<thead>
<tr>
<th>Reference</th>
<th>Time</th>
<th>Test Mode</th>
<th>TKA (Nm)</th>
<th>Uninvolved (Nm)</th>
<th>Healthy (Nm)</th>
<th>Difference Uninvolved (%)</th>
<th>Difference Healthy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berman</td>
<td>7-12 mo</td>
<td>Isokinetic, 60°</td>
<td>50.5</td>
<td>71.0</td>
<td></td>
<td>29</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13-23 mo</td>
<td>Isokinetic, 60°</td>
<td>55.9</td>
<td>69.2</td>
<td></td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;24 mo</td>
<td>Isokinetic, 60°</td>
<td>57.0</td>
<td>68.2</td>
<td></td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Huang</td>
<td>6-13 y</td>
<td>Isokinetic, 120°</td>
<td>48.4</td>
<td>60.7</td>
<td></td>
<td>20</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Isokinetic, 180°</td>
<td>36.3</td>
<td>49.9</td>
<td></td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Walsh</td>
<td>17 y</td>
<td>Isokinetic, 90°</td>
<td>57.0</td>
<td>64.5</td>
<td>80.0</td>
<td>12</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Isokinetic, 120°</td>
<td>54.5</td>
<td>63.0</td>
<td>82.0</td>
<td>13</td>
<td>34</td>
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<tr>
<td>Silva</td>
<td>2.8 y</td>
<td>Isometric, 75° of knee flexion</td>
<td>94.7</td>
<td>136.8</td>
<td></td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Berth</td>
<td>Preoperative</td>
<td>Isometric, 90° of knee flexion</td>
<td>66.3</td>
<td>81.9</td>
<td>105.0</td>
<td>19</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Postoperative (2.8 y)</td>
<td>Isometric, 90° of knee flexion</td>
<td>84.8</td>
<td>79.4</td>
<td></td>
<td>-7</td>
<td>19</td>
</tr>
</tbody>
</table>

* Percent difference calculated: (Healthy – TKA)/healthy) × 100.
† Mean age, 63; n = 68.
‡ TKA, n = 36 (mean age, 68); age-match, n = 9 (mean age, 63).
§ TKA, n = 10 (mean age, 65); age-match, n = 10 (mean age, 63).
¶ TKA, n = 31 (mean age, 66); age-match, n = 23 (mean age, 63).

Quadriceps muscle weakness in patients with OA of the knee is attributed in part to failure of voluntary muscle activation (ie, muscle inhibition). The failure of voluntary activation of skeletal muscle is defined as the inability to produce all available force of a muscle despite maximal voluntary contraction (MVC). Failure of voluntary activation is computed as 1 – (superimposed twitch at MVC/superimposed twitch at rest). Failure of voluntary activation of the quadriceps using burst superimposition is frequently reported as an index called the central activation ratio (CAR). The CAR is derived by dividing the maximal voluntary force by the total force achieved via a voluntary effort plus potential electrically elicited force. A CAR of 1.0 denotes complete activation of the muscle. Healthy older adults (66 to 83 years of age) with no known knee pathology have been reported to have a range of CAR values (0.87-1.00), with an average CAR of 0.96. When interpreting the studies using superimposed electric stimulation techniques, it is important to consider the relationship between the CAR and voluntary effort. The calculated CAR may be lower than the true CAR, and the failure of voluntary activation may be overestimated.

Failure of voluntary muscle activation plays a substantial role in the weakness that is present both before and after TKA surgery. Prior to TKA the average failure of voluntary activation is more than twice that of healthy older
TKA (85–95 Nm),\(^6,72\) strength rarely ever reaches the value of age-matched healthy individuals (105–137 Nm)\(^6,72\) or the potential isometric or isokinetic strength levels of the nonoperative knee extensor muscles (87–232 Nm).\(^4,5,6,42,52,85\) At times, the amount of residual weakness in individuals following TKA is substantial in that a general strength deficit of 20% or more is common (TABLE 2).

Some caution must be exerted when interpreting results that use the uninjured limb as a comparator. Approximately 40% of patients with unilateral TKA progress to a TKA in their nonoperative lower extremity by 10 years\(^48,65\); hence, the uninvolved knee should probably not be considered a typically healthy or unimpaired joint. Consequently, these estimates of weakness are conservative.\(^23\) Accordingly, when comparing the long-term strength outcomes of TKA to healthy age-matched groups,\(^40\) the strength deficit grows to between 30% and 48%.\(^23,52,53,85\) In summary, the quadriceps strength deficits prior to surgery are greatly compounded early after surgery and slowly recover to levels only slightly better than preoperative values. Thus, pre-existing quadriceps weakness is not resolved solely by TKA and strength values post surgery are far from age-matched normative values.

**Quadriceps Muscle Activation Failure Following TKA**

Quadriceps muscle weakness in patients with OA of the knee is attributed in part to failure of voluntary muscle activation (ie, muscle inhibition).\(^79\) The failure of voluntary activation of skeletal muscle is defined as the inability to produce all available force of a muscle despite maximal voluntary effort.\(^36,75,76\) There are 2 common techniques for equating failure of voluntary activation: twitch interpolation and burst superimposition. The twitch interpolation procedure is performed by superimposing a single or multiple pulses on various intensities of muscle contractions from 0% (resting) to 100% maximal voluntary contraction (MVC). Failure of voluntary activation is computed as 1 – (superimposed twitch at MVC/superimposed twitch at rest). A burst superimposition technique is more commonly used to determine the levels of voluntary activation\(^36\) by superimposing a train of high-voltage pulses with rapid frequency on a MVC. Failure of voluntary activation of the quadriceps using burst superimposition is frequently reported as an index called the central activation ratio (CAR).\(^36\) The CAR is derived by dividing the maximal voluntary force by the total force achieved via a voluntary effort plus potential electrically elicited force (FIGURE). A CAR of 1.0 denotes complete activation of the muscle.\(^36\) Healthy older adults (66 to 83 years of age) with no known knee pathology have been reported to have a range of CAR values (0.87–1.00), with an average CAR of 0.96.\(^49,76\) When interpreting the studies using superimposed electric stimulation techniques, it is important to consider the relationship between the CAR and voluntary effort.\(^49,76\) The calculated CAR may be lower than the true CAR, and the failure of voluntary activation may be overestimated.

Failure of voluntary muscle activation plays a substantial role in the weakness that is present both before and after TKA surgery.\(^5,7,23,57,79\) Prior to TKA the average failure of voluntary activation is more than twice that of healthy older

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**TABLE 2**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Time</th>
<th>Test Mode</th>
<th>TKA (Nm)</th>
<th>Uninvolved (Nm)</th>
<th>Healthy (Nm)</th>
<th>Difference</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berman(^6,1)</td>
<td>7-12 mo</td>
<td>Isokinetic, 60°</td>
<td>50.5</td>
<td>71.0</td>
<td>29</td>
<td>100.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13-23 mo</td>
<td></td>
<td>55.9</td>
<td>69.2</td>
<td>13</td>
<td>100.00</td>
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<tr>
<td></td>
<td>≥24 mo</td>
<td></td>
<td>57.0</td>
<td>68.2</td>
<td>16</td>
<td>100.00</td>
<td></td>
</tr>
<tr>
<td>Huang(^24,1)</td>
<td>6-13 y</td>
<td>Isokinetic, 120°</td>
<td>48.4</td>
<td></td>
<td>60.7</td>
<td>20</td>
<td>100.00</td>
</tr>
<tr>
<td>Walsh(^85)</td>
<td>17 y</td>
<td>Isokinetic, 90°</td>
<td>57.0</td>
<td>64.5</td>
<td>88.0</td>
<td>12</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Isokinetic, 180°</td>
<td>36.3</td>
<td></td>
<td>49.9</td>
<td>27</td>
<td>100.00</td>
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<tr>
<td>Silva(^72,1)</td>
<td>2.8 y</td>
<td>Isometric, 75° of knee flexion</td>
<td>94.7</td>
<td></td>
<td>136.8</td>
<td>31</td>
<td>100.00</td>
</tr>
<tr>
<td>Berth(^6,4)</td>
<td>Preoperative</td>
<td>Isometric, 90° of knee flexion</td>
<td>66.3</td>
<td>81.9</td>
<td>105.0</td>
<td>19</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Postoperative (2.8 y)</td>
<td></td>
<td>84.8</td>
<td>79.4</td>
<td></td>
<td>-7</td>
<td>19</td>
</tr>
</tbody>
</table>

* Percent difference calculated: (Healthy – TKA)/healthy × 100.
* TKA, n = 36 (mean age, 68); age-match, n = 9 (mean age, 63).
* TKA, n = 16 (mean age, 65); age-match, n = 10 (mean age, 62).
* TKA, n = 31 (mean age, 64); age-match, n = 40 (mean age, 63).
* TKA, n = 50 (mean age, 66); age-match, n = 23 (mean age, 63).

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One month following TKA, the quadriceps activation deficits are twice from preoperative levels and the average CAR of people with TKA is roughly 0.75. This level of quadriceps muscle activation failure is unusually large. As a reference, those with patellar contusions have a CAR of 0.86 and individuals with acute (6 weeks) anterior cruciate ligament tears average 0.92. As previously stated, the acute loss of quadriceps strength is dramatic and the reduction in voluntary muscle activation accounts for 65% of the variance in this loss of strength. In fact, voluntary quadriceps activation failure contributes almost twice as much to the acute decrease in quadriceps strength as compared to the amount of quadriceps muscle atrophy. Large activation deficits are of particular concern to physical therapists, as these patients typically experience only modest strength gains with exercise interventions.

It appears that voluntary activation failure can continue for an extended period of time after surgery for a subset of TKA recipients. Gapeyeva and colleagues reported average quadriceps activation levels did not improve in female TKA recipients from the preoperative time point until the sixth postoperative month. Even with upwards of 8 days of formal rehabilitation, activation levels remained lower than those of healthy subjects. A similar lack of activation improvement up to 6 months following TKA was also reported by Berth et al. Twenty patients who were scheduled for bilateral TKAs had each knee randomly assigned to receive either a subvastus or midvastus surgical approach. Quadriceps voluntary activation was assessed before surgery, and at 3 months and 6 months following surgery. All patients underwent 10 days of inpatient rehabilitation and an additional 4 weeks of outpatient therapy (though not described in the report). There was no main effect of time or surgical approach, and quadriceps voluntary activation levels were well below normal at all test points. Some others, however, report some limited activation improvements over time; however, even years after TKA, activation of the quadriceps muscle is still significantly lower than for age-matched healthy controls.

Poor quadriceps activation is a rehabilitation concern because it may blunt the potential effectiveness of voluntary exercise that relates to improving physical function. Quadriceps activation failure appears to act as a moderator between quadriceps strength and physical function in patients with OA. That is, physical function may be more limited in those people with quadriceps weakness and a higher degree of activation failure. Quadriceps Atrophy Following a TKA

Sarcopenia, the progressive loss of muscle mass with aging, is a fundamental contributor to disability in the elderly population. The quadriceps muscle activation failure present in patients with OA may be contributing to muscle atrophy, as neuromuscular inhibition prevents full muscle activation and potentially blunts the stimulus necessary to maintain muscle mass. Clinicians sense both activation failure and atrophy occur in those with TKA, though there are very few reports which have assessed muscle size changes prior to or following TKA. Quadriceps atrophy of 5% to 20% has been reported in the first month after surgery compared to preoperative values. A recent report utilizing magnetic resonance imaging (MRI) assessments on patients who are awaiting surgery describes a mean quadriceps cross-sectional area (CSA) that is quite small at 42.3 cm². Additionally, a 10% decrease in muscle size 1 month following TKA (38.2 cm²), compared to the preoperative values, has been reported. When including quadriceps atrophy into the regression model with activation failure 85% of the change in quadriceps strength in the first month after surgery is explained, though the contribution of the voluntary activation was nearly twice the relative contribution of the maximal cross-sectional area in the regression equation. The atrophy associated with TKA may be a conservative estimate of muscle loss, considering the comparisons that have been made to the uninvolved or the preoperative values. As noted earlier, the assumption that the uninvolved extremity is “normal” may not be a valid comparison in individuals with a history of OA. The maximal quadriceps CSA of patients between the ages of 41 to 75 years with a history of OA is 46.1 to 49.5 cm². This is considerably less than a comparative group between the ages of 65 and 81 years, with a maximal CSA of 63.5 to 68.1 cm². In summary, most individuals with a TKA exhibit small quadriceps CSA values that are consistent with long-term OA-induced weakness. As well, it is still unclear whether muscle strength and atrophy can return to age-matched normal values with postoperative rehabilitation interventions.

Muscle Impairments and the Related Functional Limitations Following TKA

Quadriceps muscle impairments and lower extremity OA are associated with functional limitations and slower mobility performance in older adults. The primary goals of a TKA are to decrease pain, improve functional mobility, such as walking and stair climbing, and to promote return to physical activity. TKA has been shown to be very effective in reducing the knee pain associated with arthritis, but 30% of patients report dissatisfac-
tion in their physical function 1 year after surgery. Functional outcome scores reported via questionnaires indicate an improvement in quality of life following surgery, but actual physical performance measures and the individual's perception of functional ability remain worse than the age-matched healthy population. Individuals 1 year after a TKA surgery perceived their functional ability to be approximately 80% of a group of similar age. In another self-report study only 50% of the TKA recipients considered their knee function normal compared to their healthy peers. Likewise, quadriceps weakness does not correlate well with patient perceptions of function. Self-report scores of physical function in this population tend to correspond to what patients experience (like pain or perceived exertion) when performing activities, rather than their actual ability to complete an activity. Improvement in self-report physical function is often most strongly associated with improvements in pain.

While quadriceps weakness may have a limited association with perceived functional ability, it tends to have a strong relationship with performance. Quadriceps weakness in older adults has been associated with an increased fall risk, decreased gait speed, and impaired stair-climbing ability. Like with other elderly patient cohorts, strength is an important predictor of functional abilities in patients who have TKA surgery; hence, some have suggested the need for a more aggressive and long-term postoperative rehabilitation approach. The reports of both preoperative and postoperative TKA rehabilitation outcomes suggest further modifications to the physical interventions that are needed to maximize muscle structure and functional response post surgery. However, further research, specifically randomized controlled trials, is warranted to investigate the effectiveness of strengthening exercises and manual physical therapy in individuals after a TKA.

**Preoperative Interventions**

Physical countermeasures have been successful in improving knee pain, strength, and joint stability in those with knee OA who were not yet planning to have a TKA. For those who go on to have a TKA, preoperative quadriceps strength is a strong predictor of functional performance 1 year after surgery. Furthermore, individuals with more extensive signs of OA have more quadriceps weakness. If quadriceps weakness could be addressed prior to TKA surgery, then perhaps patients might experience a better overall functional level.

Unfortunately, there is little documented success in improving the preoperative status in those planning a TKA. Physical therapy interventions prior to TKA have focused on strengthening, aerobic conditioning, and educational programs. D’Lima et al compared the effects of preoperative upper and lower extremity strength training, general cardiovascular conditioning exercises, and no intervention (control group) in individuals before and after TKA (10 subjects per group). No significant differences were observed in the 3 groups at any of the postoperative evaluations. In another study conducted by Rodgers et al, 10 patients who underwent 6 weeks of preoperative physical therapy showed no significant change in Hospital for Special Surgery Knee Rating (HSS) scores, knee ROM, isokinetic knee extension strength, and walking speed prior to surgery. Beaufre et al addressed the combined effect of preoperative strengthening exercise and education in 131 subjects scheduled for TKA. The outcome measures included gait training with an assistive device, bed mobility, and transfer training for functional recovery, and the Health-Related Quality of Life (HRQOL) questionnaire. The authors reported no significant differences in ROM, quadriceps and hamstring strength, function, or HRQOL score when compared to a control group 1 year after TKA. Finally, Rooks et al found no significant improvements in self-reported function or performance measures in those who underwent preoperative exercise training compared to those who did not (22 patients assigned per group). Considering these findings, it may be that quadriceps weakness and functional limitations are recalcitrant in those about to receive a knee replacement; however, starting quadriceps strengthening earlier (ie, in the beginning stages of OA) may be the best approach.

**Postoperative Interventions**

There is a dearth of available evidence for determining the best possible postoperative rehabilitation intervention, though a limited number of reports suggest that improvements in ROM and strength, a lowered pain level, and improvements in independence with activities of daily living have resulted from such interventions. The authors of a recent randomized controlled trial comparing a
supervised home rehabilitation exercise program to standard-care control group reported that individuals with TKA who received 12 supervised rehabilitation treatment sessions starting 2 months after surgery walked longer distances at 1 year after surgery compared to the control group, and the distance walked in 6 year after surgery; but no significant differences were noted at 1 year postsurgery. A description and comparison of published postoperative therapy protocols is provided in TABLE 3.

A longitudinal study with a more progressive and intense rehabilitation program instituted earlier after TKA (3-4 weeks postoperatively) and designed specifically to address the functional impairments following a TKA has been repeatedly reported by Mizner and colleagues at the University of Delaware.52,78 Their protocol consisted of 3 days of inpatient physical therapy, followed by 2 to 3 weeks of home physical therapy visits. At approximately 4 weeks after surgery, the patients with TKA began 6 weeks (2 to 3 times per week) of outpatient rehabilitation. Progressive, high-intensity volitional exercises were used to increase lower musculature extremity strength and improve functional ability in 40 individuals who completed this protocol (TABLE 3). At 1 month postsurgery, before treatment was initiated, knee ROM, quadriceps strength, and performance on the timed up and go (TUG) and stair climb test (SCT) were lower than they were at presurgery. The TKA recipients’ quadriceps strength decreased 62% from the preoperative value at the first month postsurgery. Following 6 weeks of rehabilitation, quadriceps strength improved significantly at each following assessment (2, 3, and 6 months postsurgery). There was also a 21% improvement in the TUG and a 40% improvement in the SCT from the preoperative test to 6 months after surgery. Finally, quadriceps strength was correlated with functional performance measures at all testing sessions and, as quadriceps strength improved, there was an enhancement in functional performance. This study clearly demonstrates that the muscle impairments and functional limitations can be reversed following a TKA.52

There is also some evidence that the addition of neuromuscular electrical stimulation (NMES) to a physical therapy protocol could enhance the speed and ultimate recovery of quadriceps strength after TKA. In 2 case report series from the same group, the addition of high-intensity NMES to the quadriceps muscle produced strength gains that exceeded previously published outcomes40,78 (NMES specifications described in TABLE 3). The data were also suggestive of a positive dose-response relationship for NMES. Those patients who achieved a higher percentage of their knee extension maximal voluntary isometric contraction torque with NMES contractions had greater gains in strength.78 These results suggest that NMES early after TKA may help resolve quadriceps activation failure and mitigate quadriceps muscle weakness. When considering the low quadriceps activation in this patient population early after surgery, the addition of NMES to augment volitional strengthening exercises could be a useful adjunct to reha-

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**TABLE 3**

<table>
<thead>
<tr>
<th>A Comparison of Therapeutic Exercise Rehabilitation Approaches Following TKA</th>
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</thead>
<tbody>
<tr>
<td><strong>Avramidis</strong></td>
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<tr>
<td>Start of therapy</td>
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<tr>
<td>Frequency</td>
</tr>
<tr>
<td>Number of visits (duration)</td>
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<tr>
<td>NMES*</td>
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<tr>
<td>Bike</td>
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</tbody>
</table>

**Core exercises**

- Quadriceps sets
- Hamstring sets
- Straight-leg raise
- Hip abduction
- Standing terminal extension
- Step-ups/downs
- AROM/AAROM
- Seated knee extension
- Wall squats/standing squats
- Standing hamstring curl
- Lunges
- Walking
- Non–weight-bearing ROM
- Ankle pumps
- Sit-to-stand
- Walking backward, marching, side step

**Abbreviations:** AAROM, active assistive range of motion; AROM, active range of motion; NMES, neuromuscular electrical stimulation; ROM, range of motion; TKA, total knee arthroplasty.

* NMES parameters: 2500-Hz triangular-wave alternating current (AC), 12-s on-time, 80-s off-time, 2- to 3-s ramp-up time, knee flexed to 60°, 10 isometric contractions, dose set to maximally tolerated by the patient, large (7.6 × 12.7 cm) self-adhesive electrodes placed on motor points of the quadriceps femoris muscle.
bilitation, especially for those people who are very weak.

The addition of NMES even earlier than 4 weeks may also be beneficial. A randomized control study by Avramidis et al. investigated the effect of 4 hours per day of NMES (40 Hz, 300 μs) to the vastus medialis, commencing on postoperative day 2 and continuing for 6 weeks following surgery. This resulted in improved walking speed, though no changes were noted in the HSS or in an index of physiological cost. A recent case report also describes the use of NMES, initiated on postoperative day 2 for a 6-week period, and reported strength gains in the first month after surgery compared to preoperative values. In summary, outpatient rehabilitation after a TKA seems to be superior to no intervention at all. These studies suggest that muscle impairments and functional limitations can be reversed following a TKA. But additional research is necessary to determine the optimal mode, intensity, and duration of physical therapy needed to mitigate the muscle impairments and related functional limitations following a TKA.

**RECOMMENDATIONS AND TKA CLINICAL GUIDELINES**

The recommendations and clinical guidelines described below are derived from the best available evidence, but additional research, specifically randomized controlled trials, is needed to optimize short- and long-term outcomes for individuals after a TKA. Nevertheless, recipients of TKA should respond favorably to similar therapeutic exercise guidelines as suggested by the American College of Sports Medicine (ACSM) for older individuals. That is, progressive resistive training of major muscle groups (especially of the lower extremities) should be performed 2 to 3 times per week and aerobic training 3 times per week for 30 to 40 minutes. The aerobic training for those with a TKA, however, should include walking on flat ground initially, adding hills, and negotiating stairs. Higher-level aerobic exercises that minimize impact to the knee, such as swimming, cycling, water aerobics, and power walking, are also recommended. Recreational activities with high joint loads, such as skiing, tennis, and hiking, should be performed with caution and only occasionally. TKA recipients are strongly cautioned to avoid even the lowest-level impact recreational and athletic activities until their quadriceps and hamstring muscles are rehabilitated sufficiently. Specific recommendations derived from the 1999 Knee Society Survey have been used to develop a consensus recommendation for athletics and sports participation for those with a TKA (TABLE 4). Despite these guidelines, many TKA recipients still experience significant difficulty in performing activities that require higher-level mobility skills commensurate with recreational activities.

Therapeutic exercise guidelines following a TKA are traditionally focused on the control of pain and swelling, while improving ROM and functional mobility. More progressive, high-intensity exercises may be necessary to address lower extremity muscle size, activation and strength deficits, along with functional mobility early following surgery. The use of NMES along with an exercise program has demonstrated improved quadriceps strength and activation and is recommended early in a rehabilitation program. Resistance training (60% of the 1-repetition maximum) has been demonstrated to induce increases in strength in the elderly. Therefore, it may be necessary to increase the lower extremity strength training to at least that level of intensity for 1 to 3 sets of 10 to 20 repetitions to overcome the recalcitrant muscle impairments which may be present 6 months to 1 year following TKA. The **APPENDIX**
provides specific guidelines relative to a progressive rehabilitative program for those following a TKA. These recommendations are used to address the pertinent muscle impairments in addition to enhancing mobility.

The protocols mentioned by Moffet and colleagues and the investigations from Snyder-Mackler’s laboratory at the University of Delaware are combined with the ACSM guidelines into 4 phases and the timelines are a guide for progression into the next phase. Modifications to this program are instituted immediately if adverse knee joint reactions (eg, pain, swelling) occur. Decreasing the intensity, frequency, and duration of the resistance exercise typically resolves any adverse knee response. In phase I following a TKA, patients receive home health or outpatient physical therapy 2 to 3 times per week for 2 to 3 weeks after inpatient discharge. The emphasis of physical therapy in this phase is on edema management, improving ROM, starting a strengthening program, and improving functional independence. At approximately 3 to 4 weeks post-surgery, or when goals are met, the patients start phase II, which consists of outpatient physical therapy 2 to 3 times per week for 4 to 6 weeks. Augmentation of the quadriceps muscle’s activation following TKA should be emphasized early in this rehabilitation phase to help restore quadriceps muscle strength. Physical therapy treatments should employ the concepts of progressive high-intensity volitional exercises with NMES to increase strength and quadriceps muscle activation. At 10 to 12 weeks postoperatively or when the criteria for progression are met, such as ROM from 5° or less to 110° or greater, minimal pain and edema, and voluntary quadriceps muscle control, patients progress to phase III of the rehabilitation program. Phase III includes a semi-independent period of 4 to 8 in-clinic visits over 3 to 4 weeks, with a goal to improve strength and progress to an independent phase (phase IV), with clinical follow-up visits for another 8 weeks. In addition to a warm-up and functional endurance exercises, this program places an emphasis on strengthening exercises for the lower extremity. In an attempt to mitigate the muscle impairments, progressive, moderately high-resistance exercises are used. Most often individuals with TKA can increase the intensity of exercise after 3 sets of 10 repetitions are completed correctly without undue fatigue.

**SUMMARY**

Muscle impairments that exist following a TKA may persist for years. Improving quadriceps strength may mitigate these impairments and result in improved functional outcomes. An emphasis on muscle weakness countermeasures, like resistance exercises and NMES, is needed. Further research is required to determine the optimal exercise prescription that can safely augment the return to near-normal levels of activity and function for individuals who had TKA surgery.

**REFERENCES**

6. Berth A, Urbach D, Awiszus F, T aylor PN, Swain ID. Improvement of knee response. In phase I following a TKA may persist for years. Improving quadriceps strength may mitigate these impairments and result in improved functional outcomes. An emphasis on muscle weakness countermeasures, like resistance exercises and NMES, is needed. Further research is required to determine the optimal exercise prescription that can safely augment the return to near-normal levels of activity and function for individuals who had TKA surgery.


APPENDIX

REHABILITATION GUIDELINES FOLLOWING A TOTAL KNEE ARTHROPLASTY

Phase I: Home health (or outpatient) physical therapy (2-3 times per wk, 2-3 wk)

Goals:
1. Increase range of motion (ROM)
2. Decrease edema and pain
3. Gait training
4. Independence with activities of daily living (ADLs)

Exercises:
1. Seated or supine knee active range of motion (AROM)
2. Alternated ankle dorsiflexion and plantar flexion
3. Quadriceps sets


Criteria for progression to exclusively outpatient physical therapy:
   a. AROM approaching 90° of knee flexion
   b. Minimal pain/swelling
   c. Independence in mobility in and out of the home

**Phase II: Outpatient physical therapy (2-3 times per wk, 4-6 wk)**

**Warm-up (15-20 min):**
1. Exercise bike (10-15 min), start with forward and backward pedaling with no resistance until there's enough knee ROM for a full revolution. Seat height may be lowered for progression of ROM
2. Seated or supine knee AROM (flexion and extension)
3. Alternated ankle dorsiflexion and planter flexion
4. Passive knee extension stretch
5. Patellar and knee mobilizations

**Specific strengthening (10-15 min), 1-3 sets of 10 repetitions:**
1. Neuromuscular electrical stimulation (NMES) to augment quadriceps muscle activation. NMES parameters: 2500-Hz triangular-wave alternating current, 12-s on-time, 80-s off-time, 2- to 3-s ramp-up time, knee flexed to 60°, 10 isometric contractions, dose set to maximally tolerated by the patient, large (7.6 \times 12.7 \text{ cm}) self-adhesive electrodes placed on the motor points of the quadriceps femoris muscle
2. Quadriceps sets
3. Straight-leg raises (assistance as needed, goal to perform without a knee extension lag)
4. Hip abduction (side lying)
5. Standing leg curls
6. Seated knee extension
7. Standing terminal knee extension from 45° to 0°

**Functional exercises (10-15 min):**
1. Step-ups, 5-15 cm, or climbing a flight of stairs
2. 45° wall slides or sit-to-stands
3. Walking backward, side step, march, or crossover steps
4. Walking through an obstacle course
5. Gait training emphasis on heel strike and push-off at toe-off

**Endurance exercises (5-20 min):**
1. Walking
2. Stationary cycle

**Cool-down (10 min):**
1. Ice and compression as needed
2. Gentle stretching and ROM

**Criteria for progression:**
   a. Voluntary quadriceps muscle control or 0° knee extension lag
   b. AROM 0° to greater than 105° of knee flexion
   c. Minimal to no pain and swelling

Exercise progression:
   a. Exercises are to be progressed once the patient can complete 3 sets of 10 reps of the exercise correctly and feels maximally fatigued
   b. Add 0.2- to 1.5-kg weights to the exercises
   c. Increase step height if showing good concentric/eccentric control
   d. Increase wall slides to 60° and to 90°

**Phase III: Semi-independent phase (1 time per wk or biweekly, 4-6 weeks)**

**Exercises:**
1. Continue all exercises in phase I as a home exercise program or a gym membership

**Warm-up (15-20 min):**
1. Seated or supine knee AROM (flexion and extension)
2. Alternated ankle dorsiflexion and planter flexion
3. Passive knee extension and hamstring stretch
4. Exercise bike or treadmill walking (perceived exertion should be light)

**Strengthening (20-30 min, 1-3 sets of 10-20 reps of any of the following):**
1. Leg press varying working ROM*
2. Leg extension: ROM, 90°-0° or 90°-30° for extension*
3. Standing or sitting leg curls*
4. Standing heel raises*
5. 4-way hip machine or (rubber band or ankle weights for resisted hip ROM)*
6. Sit-to-stand free weights in hands
7. Weight-bearing exercises with emphasis on eccentric control
8. Upper extremity strength training optional
   *Use a 5- or 10-repetition maximum to determine 60%-70% resistance of 1-repetition maximum
   *Machine weights

**Functional exercises (10-15 min):**
1. Step-ups 5-15 cm or climbing a flight of stairs
2. 45° to 90° wall slides or sit-to-stands, hold 5-10 s
3. Walking backward, side step, march, or crossover steps

**Endurance exercises (5-20 min, alternate between walking and biking):**
1. Walking, change speed and incline
2. Biking

**Criteria for progression:**
Exercises are to be progressed once the patient can complete 3 sets of 10 reps of the exercise correctly and feels maximally fatigued

**Exercise progression:**
   a. Reassess 65%-70% of maximal effort biweekly to determine progression of resistance
   b. Increase step height if showing good concentric/eccentric control
   c. Increase wall slides to 60° and to 90°

**Phase IV: Independent phase (visits scheduled 1 time/wk or biweekly for 8 wk, or as needed, to reassess strength, ROM, and function, and to progress exercises)**

Exercises (continue all exercises, 1-3 sets at 10-20 reps, as a home program or a gym membership 2-3 times/wk)