Exercise programs for hip and knee pain disorders

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Introduction

Exercise-based management of hip and knee injuries involves strategically applying stress to the relevant tissue to drive desired adaptations. This process has been defined as the "SAID Principle" (Specific Adaptation to Imposed Demand), and it should underpin continuous clinical reasoning throughout management. In the context of rehabilitation, exercise prescription (ExRx) is used to address any limitations identified as barriers to function, participation and performance. When the principle of SAID is applied, the ExRx emerges from the intersection of the personal patient's current presentation and their goals.

In general, rehabilitation goals will broadly cluster around range of motion (ROM), force output (strength), energy system development (ESD), and other tissue-specific adaptations. There are also other clinical objectives such as pain, health or improved performance where the causal impact of ExRx is less clear. While important, the role ExRx plays in these outcomes is poorly understood at this time. This chapter aims to provide an ExRx framework that allows the clinician to treat hip and knee disorders with a sound rationale and evidence base. Exercises can be isolated to a single joint or involve the whole kinetic chain and they can be performed non-weight-bearing or weight-bearing.

Clinical Reasoning for the Application of Exercise Programs

A Framework for Exercise Prescription

The fundamental principles of exercise prescription must drive exercise selection, dosage, and progression. The idea of progressive overload complements the SAID principle to achieve the desired goals. As structures adapt to the demands they are exposed to, future programming of the exercise program must be progressed to ensure these adaptations continue. ExRx is flawed when the stress becomes "different" instead of "progressive." Two examples where this can occur are progressing from constrained to compound exercises or adding instability to an exercise in place of overload. In the first example, the individual can "cheat" and select a movement solution that shifts force away from the target tissue and in the second, there is no actual overload (Sigward et al., 2018; Lawrence & Carlson, 2015). In both cases, the changes lead to a decrease in the load through the relevant tissue and thus failure to achieve the goal of progressive overload.

The particular exercise chosen is only a small component of the overall exercise prescription process, which requires the manipulation of multiple factors. This error is observed when resistance training and strength training, which are not synonymous, are conflated. Strength training involves the deliberate process of increasing the force that can be produced against some external resistance (Schoenfeld et al., 2021). In contrast, resistance training is merely the process of adding resistance to a movement. This may not hit the minimum effective dosage necessary to see adaptations in strength but can still lead to improved function and decreased pain through processes such as graded exposure or learning of the task (Table 19.1).

A review of exercise adaptations exceeds the scope of this chapter, but the general goals of strength, hypertrophy, and connective tissue adaptation deserve attention. Resistance training has traditionally been prescribed based on repetition "zones" that were proposed to align with specific adaptations, however this model may be overly simplistic. A recent review by Schoenfeld et al. (2021) suggested that strength adaptations seem to favor heavier loads largely independent of volume. And hypertrophy appears to be more independent of load once a minimum threshold (~30% 1 repetition maximum (RM)) is met, with adaptations tending to reflect the effort and total volume load. Despite this, Schoenfeld et al. (2021) still suggest moderate intensities as generally the most practical approach for hypertrophy (Table 19.2). Connective tissue adaptations require an understanding of prescription based on the SAID principle. In tendons, a systematic review and meta-analysis demonstrated that external loads exceeding 70% of 1RM were necessary to cause adaptation (Bohm et al., 2015). Further work done by Arampatsis et al. (2020) shows this threshold may be even higher, with loads of over 90% MVC necessary to achieve optimal strain in the Achilles tendon. Aside from muscle, bone and tendon adaptations there are also neural changes in the central nervous system

TABLE 19.1 Training Variables

Training Variable	Measure	Prescription	Impact
Intensity	External load added or torque at joint	% of rep max (85% RM) or reps at load (e.g., 5RM)	See Table 19.2
Effort	Proximity to failure	Reps in reserve or rating of perceived exertion	Fatigue, motor unit recruitment, hypertrophy
Tempo/Velocity	Speed of movement	Metronome or descriptive term (e.g., maximal, controlled, etc.)	Stress & strain on tissue, accumulation of fatigue
Volume	Total repetitions per workout	Assigned by sets & rest periods	Muscular, energetic, & connective tissue adaptations
Rest	Time	Time between efforts	Fatigue & force capabilities on subsequent sets, motor unit recruitment
Frequency	Sessions per time period	Weekly	Total dosage & recovery abilities

(Modified from Lorenz & Morrison, 2015.)

TABLE 19.2 Training Intensity

Intensity Training Zones	Goal	Intensity as % 1RM (Rep Range)
Zone 1	Hypertrophy, skill, work capacity, rate of force with high rate	<50% (>15 reps)
Zone 2	General training (hypertrophy sweet spot)	50%–75% (10–15 RM)
Zone 3	General strength, connective tissue, hypertrophy, rate of force with intent	75%–86% (5–10 RM)
Zone 4	Max strength, connective tissue, hypertrophy	90%+ (1–4 RM)

(Modified from Lorenz & Morrison, 2015; Schoenfeld et al., 2021; Haff & Triplett, 2016.)

that affect the response to overload. Specific adaptations to exercise, such as adding visual or auditory cues and timing to repetition execution can improve neural responses (Rio et al., 2016). In summary, it is important to determine what the desired adaptations are through a thorough evaluation and assessment and ensure programming reflects these goals by honoring the SAID principle.

Exercise Prescription

Exercise selection requires a few fundamental principles to guide the process. First, the external load imposed by the programming is only part of what determines the internal loads experienced by the tissues. Torque at the joint is the product of the moment arm (distance from resistance to joint), the total force applied, and the angle it is applied at. Because of this, all of these factors must be considered when selecting an exercise. This chapter uses a continuum model to give the sports medicine professional a loose framework for identifying and selecting movements.

Exercise prescription tends to be full of vaguely defined concepts with terms like "functional" used in a manner so broad as to lose any real meaning. Biomechanically unsound concepts like open kinetic chain and closed kinetic chain also fall into this category as they do not accurately represent the forces experienced by the system (Knudson, 2007). Because of these clarity issues, this chapter will approach exercise selection based on general movement biases and the concept of constraints. A movement bias is operationally defined as the predominant joint(s) around which the movement is organized. Figure 19.1 shows the "Hip Hinge Continuum" as a method for categorizing exercises (John, 2013). This model is a way to understand and organize compound exercises based on the relative contribution of the hip and knee. The clinician can orientate the specific exercise to the continuum, in order to have a reasonable approximation of its demands. This allows the clinician to determine whether the exercise selected is likely to address the stated goals. As a general heuristic "hinge" movements shift demands to the hip while "squat" movements have a greater knee demand. Using this continuum allows the clinician to initially categorize an exercise as well as come up with progressions and regressions for it. This can then be compared to the literature on muscle demands during exercise in order to predict actual demands. It must be stressed that these data frequently contain confounders and do not necessarily represent actual mechanical tension on the muscle or tendon for each exercise. Reports on muscular demands and progression of exercise (often based exclusively on EMG data) should be interpreted with caution since examined loads are not normalized and EMG can be problematic. As a result, these studies may give a general idea of muscles recruited with the lift, but shouldn't be the main driver of decision-making as they are unlikely to predict actual internal loads or eventual adaptations. A clear example of this can be seen in the study by Delmore et al. (2014), where loaded side-lying adduction exercise was compared to bodyweight sumo squats. There was a significant difference in relative intensity for the adductor muscles in these exercises and the sumo squat showed a low level of activity. This is contrasted by biomechanical modeling showing over 50% of the net hip extension moment comes from the adductor magnus during a loaded squat, which agrees with findings from a 10-week intervention study that found the adductors were the most hypertrophied muscle group after a squat-based training program (Vigotsky & Bryanton, 2016; Kubo et al., 2019)

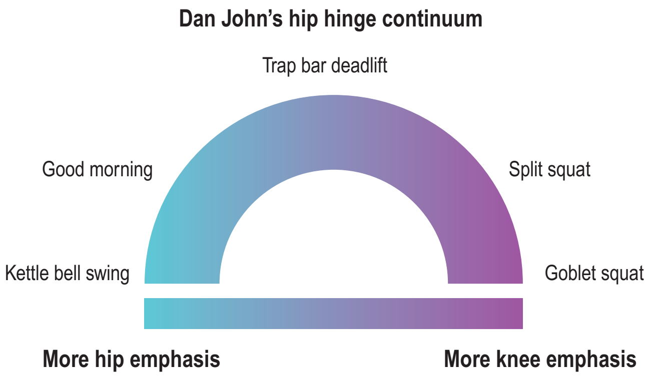

FIGURE 19.1
The "Hip Hinge Continuum" as a method for categorizing exercises.
(Modified from John, 2013.)

Evidence supports the application of localized exercises for the injured or painful area, i.e., quadriceps exercises for patellofemoral pain, hamstring exercises for biceps femoris strain/tear, or gastrocnemius and soleus exercises for Achilles tendinopathy. Less constrained exercises are commonly used to improve function and performance further and integrate the tissue/motion segment back into a compound movement. The hip displacement continuum allows

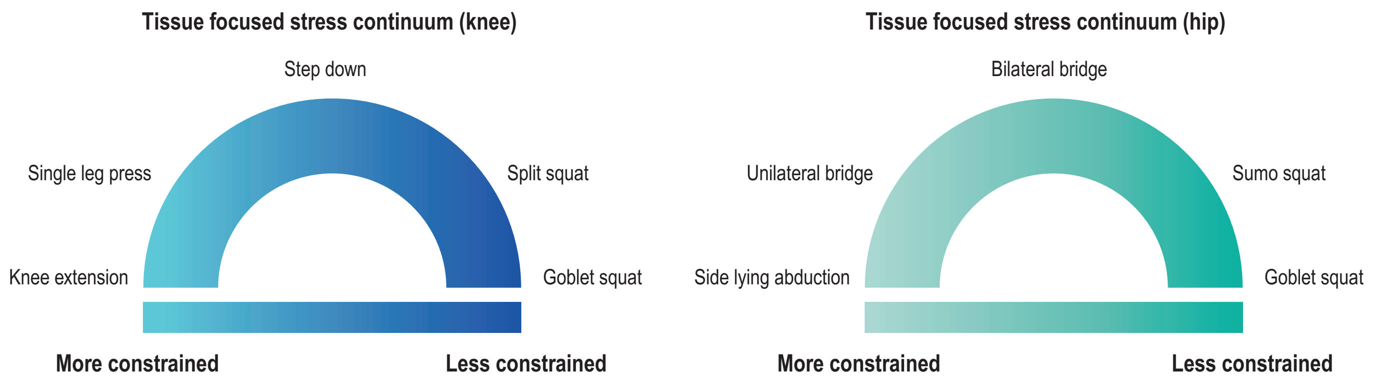

FIGURE 19.2
Examples of the tissue focused stress continuum principle.

for the global categorization of compound lower body exercises. This categorization can be further refined by introducing the idea of constraints that determine the degrees of freedom available for that movement (Figure 19.2). An exercise can be considered highly constrained when the performance of the movement can only be accomplished by limited options such as during single-joint movements. This reduction in movement options ensures that any loads placed on the system are constrained to the selected tissue. For instance, during a constrained Nordic hamstring exercise, the hamstring is significantly loaded while there is very little hamstring load during a more unconstrained squat (van Dyk et al., 2019; Vigotsky & Bryanton, 2016; Kubo et al., 2019). The use of constraints allows the clinician to prescribe movements that have a higher probability of loading relevant tissue in order to ensure SAID is occurring at the desired system and level. In contrast, a less constrained exercise can be used to load the kinetic chain in order to ensure integration of local adaptions back into larger movement patterns.

Which Type of Contraction Should be Applied During Exercise Programs?

There is extensive literature trying to determine which type of contraction, i.e., eccentric, concentric, isometric, is more effective for improving pain and related function in lower limb pain, particularly in tendinopathies. To date, it seems that eccentric, concentric or isometric contractions exhibit similar effects in individuals with tendinopathies, probably because of these tissues' non-contractile properties (Bohm et al., 2015; Clifford et al., 2020). It also appears that when the maximal load or effort is matched, morphologic changes in the muscle are equivalent albeit through slightly different pathways (Franchi et al., 2017). Therefore, ExRx should generally use combined movements with isolated contractions being implemented under specific circumstances, e.g., isolated isometrics to avoid painful ROM, accentuated eccentrics as part of a progressive loading exercise program according to patient presentation and established goals.

Progression of Exercise Loading

Tissue stress is probably the key factor for properly designed exercise programs. Knowledge of muscle and connective tissue properties, force applications, tissue injury (bone, ligament, tendon, muscle, nerve) and tissue healing principles and timelines (e.g., inflammation, proliferation, maturation) is an important precursor for developing a suitable and safe exercise program. The main difference faced by the clinician in ExRx is the presence of pathology which results in a more volatile presentation. Because of this, symptom response and exercise intensity as a percentage of maximal voluntary contraction (%MVC) must be considered.

A variety of exercise programs have been investigated for treating hip and knee problems. A unique problem that clinicians face in ExRx is how to dose exercise in the presence of pain. For instance, eccentric strength training, while potentially effective in the management of hip-knee problems, can also be associated with higher rates of delayed onset muscle soreness (DOMS) (Morawetz et al., 2020). There have been a number of models for how to solve this problem. Alfredson et al. (1998) recommended an increase in load when pain or discomfort during the exercise for Achilles tendinopathy decreased. Stanish et al. (1986) proposed that the appropriate load for tendinopathy is that one when pain or discomfort is experienced in the last set of repetitions of the exercise. Based on the current body of literature the appropriate clinical question is "what level of pain or discomfort should be permitted?" While Silbernagel et al. (2001) allowed activity-based pain when treating tendinopathy to reach 5 (moderate intensity) on a numerical pain rate scale, clinicians should consider that pain intensity is a subjective outcome and so a fixed acceptable number may not be realistic. A meta-analysis by Smith et al. (2017) concluded that painful exercises offer better, although small, benefits at short-term (moderate quality of evidence) and equal long-term outcomes over pain-free exercises in the management of chronic musculoskeletal pain. So, while pain during exercise is not a barrier for successful clinical outcomes, it must be properly monitored (Smith et al., 2017). This is consistent with postoperative exercise programs being progressive and graded according to the stage of tissue healing while avoiding any aggravation of pain, swelling, or a deterioration of other clinical signs such as ROM, strength and function of the patient.

Exercise intensity in ExRx can be based on objective measures such as using a repetition maximum or maximal isometric test, or even velocity-based estimates of the patient's 1RM. However, this is often complicated by tissue healing status which makes subjective estimates of effort like repetitions in reserve (RIR) an appealing alternative. This is an approach where the clinician asks the individual to make an estimate of how many more repetitions, they believe they could have completed if they hadn't stopped the set. This can be estimated at any time but is typically done immediately following the end of the set. A numerical estimate is given based on the patient's perception of their ability and recorded as "estimated reps in reserve." This approach has been proposed as an acceptable alternative to the use of more traditional methods with acceptable reliability in several studies (Helms et al., 2016; Lovegrove et al., 2021). It should be noted, however, that this approach almost always results in a lower intensity than intended since most subjects underestimate their abilities and seem to frequently anchor the perception of effort on discomfort (Steele et al., 2017; Armes et al., 2020). To mitigate these downsides, it is recommended that those using this approach take the following steps. Only use estimates of 2–3 RIR or less to make decisions and regularly use a set performed to momentary muscular failure (MMF) (inability to perform a subsequent rep without loss of form) to anchor the patient's perception of maximal effort (0 RIR) to what it actually feels like (MMF). All patients should be instructed clearly to separate effort from discomfort or pain, and RIR use should be limited to moderate or lower rep ranges.

Periodization of Exercise

Periodization is the sequential planning of training to achieve desired adaptions at specific time points (Plisk & Stone, 2003). This is done by adjusting training parameters to expose the trainee to the stressors that will result in the desired adaptation at the appropriate time points (Plisk & Stone, 2003; Evans, 2019; Lorenz & Morrison, 2015). In spite of its popularity it is surrounded by mystique and is poorly understood. For a detailed discussion of this subject and its application to rehabilitations see Lorenz & Morrison (2015), but fundamentally it is about manipulation of intensity and volume. Three broad categories of periodization have emerged: linear, block, and undulating. While there are differences, the foundational aspects are the same. The most traditional method is linear, which starts with higher volumes and lower intensities and then progresses to higher intensities and lower volumes in a progressive and sequential manner (Evans, 2019; Lorenz & Morrison, 2015). Block periodization uses discrete time periods to focus on addressing a specific aspect while secondary capacities are stimulated just enough to maintain a training effect. Finally, undulating approaches alternate between a higher volume or a higher intensity emphasis on a more frequent basis than the other two (typically progressed daily or weekly) (Evans, 2019., Lorenz & Morrison, 2015). While there are many significant concerns with periodization dogma, the principles of progressive overload and SAID appear to be "eminently sensible" (Kiely, 2012). For rehabilitation it is very hard to beat the model laid out by Al Vermeil in his training hierarchy (Figure 19.3). This model typically starts with building general physical capacity to prepare the individual

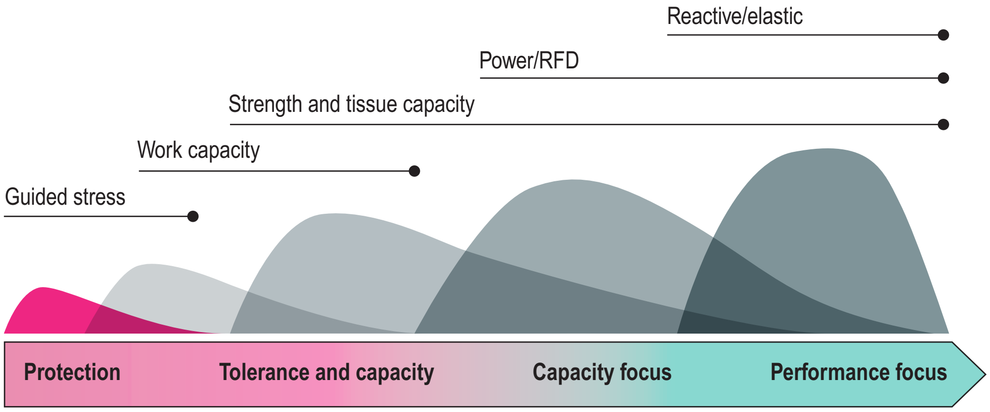

FIGURE 19.3
Vermeil's hierarchy adapted for rehabilitation.
(From Morrison, 2020).

to tolerate the future training. In rehabilitation it often becomes necessary to add a tissue protection phase before work capacity when there are contraindications based on tissue healing timeframes. It then continues to progress through a classic linear approach building from strength to the rate at which the force is expressed to the realization of this training by working on reactive ability. This process has each phase preparing the individual for the next one in a logical and sequential manner with return to performance at the end (Panariello et al., 2017). While this model will not always suit, it is also recommended that the rehabilitation professional have a general plan for progression of exercise that honors the principles of progressive overload and SAID. This allows continued progress towards the overall goal without being distracted by necessary regressions and lateralizations that may occur along the way.

Adherence to Exercise Programs

Since exercise adaptations proceed in a dose response manner, adherence to the exercise program plays a major role in outcomes. Many factors modify adherence, including the patient's self-efficacy, personal beliefs, accessibility or fear-avoidance behaviors. The healthcare professional may enhance adherence to exercise programs by adapting their program to these limitations. Self-efficacy has been defined as "the belief and conviction that one can successfully perform a given activity" and should play a substantial role in the way the clinician approaches ExRx for the individual (Fletcher & Banasik, 2001). One potential efficacy modifier is the number of exercises prescribed, with emerging data showing a single exercise elicited similar outcomes to multiple exercises (Littlewood et al., 2016). Emerging data support these ideas, such as a meta-analysis by Nicolson et al. (2017), who found behavioral graded exercises, which gradually increase intensity and exercise integration into ADLs, were better at increasing patient motivation than other strategies such as counseling, action coping plans or audio/video exercise cues. Clinicians should identify and consider patients' preferences and appropriate progressions to improve exercise adherence.

Evidence for Exercise for Hip and Knee Disorders

Moderate to strong evidence supports the use of exercise programs for addressing pain and improving function in conditions of the hip and knee such as patellofemoral pain (Clijsen et al., 2014), knee osteoarthritis (Bartholdy et al., 2017), and meniscus tear (Swart et al., 2016), as well as potentially reducing the risk of overuse injuries (Lauersen et al., 2014, 2018). Most clinical practice guidelines recommend exercise programs as a first-line intervention for the management of patellofemoral pain (Wallis et al., 2021), knee osteoarthritis (Arden et al., 2021), or hip osteoarthritis (Cibulka et al., 2017). Similarly, strengthening exercises are also strongly recommended in clinical practice guidelines after anterior cruciate ligament (ACL) reconstruction (Andrade et al., 2020), and pain with meniscal injury and other associated cartilage lesions (Logerstedt et al., 2018).

Various types of exercises including stretching, stabilization, strengthening, motor control, proprioceptive, graded activity and aerobic are described in the literature for hip and knee conditions. Saltychev et al. (2018) found that all these exercise types exhibit similar effects for decreasing pain symptoms in individuals with patellofemoral pain: strengthening (decrease pain on a 100-point scale −65.0, 95%CI −87.7 to −48.3), weight-bearing (−40.0, 95%CI −49.4 to −30.6), neuromuscular facilitation combined with aerobic exercise and stretching (−60.1, 95%CI −66.9 to −54.5), or postural stabilization (−24.4, 95%CI −33.5 to −15.3) exercises. The type of exercise should be adapted to patient characteristics and based on clinical reasoning.

Are There Subgroups of Patients Who Will Benefit from Exercise?

Classification systems have been proposed throughout the literature, by developing clinical prediction rules, suggesting that subgroups of patients may respond differently to exercise programs; however, it is unknown which individuals with hip or knee problems would benefit most from which type of exercise. In fact, clinical prediction rules have not been validated with high-quality randomized clinical trials and currently cannot be recommended (Walsh et al., 2021).

Potential Effects of Exercise

Exercise may be effective for reducing pain and improving function through two mechanisms. The first hypothesis is that exercise leads to positive effects by changing connective tissue, neural tissue and even bone properties. For example, Gérard et al. (2020) observed that an eccentric strength-training exercise program induced architectural adaptations on the long head of the biceps femoris muscle and an increase in eccentric hamstring strength. However, while muscular changes could be able to explain improvements in function, any extrapolation to changes in pain are tenuous at best.

Exercise has been shown to exhibit an analgesic effect which is not fully understood but is thought to be due to multiple factors including graded exposure, local changes, descending pathways, and central nociceptive changes (Vaegter et al., 2014). The effects of exercise in individuals with chronic pain exhibiting central sensitization might be slightly different and, therefore, opposite clinical outcomes may occur. For instance, inappropriate exercise may induce hyperalgesia instead of hypoalgesia in a patient with chronic pain (Daenen et al., 2015), and hyperalgesia may also cause ExRx that is innocuous from a traditional perspective to be detrimental as well. An ongoing consideration of the patient's pain experience is a necessary component of proper exercise progression.

Types of Exercises

Stretching Exercises

Flexibility and the role of stretching exercises have a conflicting body of evidence, an exploration of which is also beyond the scope of this chapter. Stretching includes multiple approaches such as static, ballistic, proprioceptive neuromuscular facilitation, post-isometric relaxation, and activated isolated stretching. In general, current data do not support the idea of tissue changes during stretching with an alteration in tolerance to stretch explaining most ROM changes seen (Weppler & Magnusson, 2010). In contrast to this, the body of evidence points to eccentric training through full range leading to similar ROM changes as stretching with associated performance adaptations (O'Sullivan et al., 2012). As a result, it is suggested, when time is limited, resistance training with a ROM emphasis should be used as the primary approach to increasing ROM. If stretching is included, dosage recommendations for duration and frequency are heterogeneous, but a general target of 5 times a week accumulating at least 5 minutes of stretch seems indicated (Thomas et al., 2018).

Independent of the form of stretching applied, the common assumptions that stretching prevents injury, increases muscle strength and/or reduces delayed muscle onset soreness after exercise do not appear to be supported by the literature. Two previous Cochrane reviews concluded that evidence did not support that stretching exercises reduce the risk of lower extremity limb soft-tissue injuries (Yeung et al., 2011) or prevent or reduce muscle soreness after exercise (Herbert et al., 2011). Similarly, the effect of stretching exercises on muscle strength has been found to be trivial (Konrad et al., 2021).

Strength and Hypertrophy Training

Strengthening exercises for the management of lower extremity conditions have been investigated, although evidence of effectiveness is generally inconclusive in many of these (Geneen et al., 2017). The progression of load is critical for any strengthening exercise program where strength changes are the goal. This is an issue since many times progressive overload is failed such as the report by Minshull and Gleeson (2017) that principles of training were inconsistently applied and inadequately reported in clinical trials investigating exercise programs in people with knee osteoarthritis.

In strength training the consideration of intensity, duration, and frequency of the exercise is important for appropriate ExRx. The energy demands and volume load of the exercise and session can be modulated by varying intensity (%RM), sets, repetitions, rest intervals, velocity and intent. In line with the more traditional zones discussed previously, Kraemer & Ratamess (2004) recommended 1–6 repetitions for strength, 6–12 repetitions for hypertrophy, and 12–15 repetitions for endurance, based on fatigue towards the end of the stated number of repetitions (Kraemer & Ratamess, 2004). More recently, Schoenfeld et al. (2014) observed that a hypertrophy (3 sets of 10 repetitions with a 90-sec rest) and a strength (7 sets of 3 repetitions with a 3-min rest) program were equally effective for muscle size (hypertrophy) but the latter was superior for enhancing maximal strength. The weekly frequency and volume of training is also important for appropriate progression. Current evidence indicates that training twice a week promotes superior strength outcomes than training once a week but there may be limited benefits associated with higher frequencies (Schoenfeld et al., 2019). For hypertrophy a goal of 10 sets per week per muscle group with a weekly frequency that makes this volume easily achieved seems consistent with current evidence (Schoenfeld et al., 2017, 2019).

Exercises for the Lower Extremity

The exercises chosen must be based on the adaptations desired. As these neuromusculoskeletal adaptations occur, the practice of the daily tasks and movements specific to the population must also be considered as these are two distinct goals. When treating subjects with a more volatile presentation, such as higher levels of pain or post-surgery, a starting point substantially less than what can be tolerated may reduce the probability of overshooting their capacity. This allows the clinician to build up to a level of tolerance instead of overdoing it from the start. It also offers the opportunity to take advantage of the repeated bout effect where initial exercise conveys a protective aspect to exercise-related soreness in subsequent bouts. The following section reviews some of the more common exercises along with EMG data and their place in the continuum.

FIGURE 19.4
"Clam shell position" with a band in a "side-bridge" position.

Gluteal Musculature

Globally, most movements on the "hinge" side of the continuum will involve the gluteals, although they also play a significant role in squatting. Several exercises for the gluteal musculature (i.e., gluteus maximus, gluteus medius, and gluteus minimus) will be discussed, although gluteal muscles are used during most compound lower body exercises.

The gluteus medius and minimus musculature can be strengthened in both non-weight-bearing (i.e., side-lying hip abduction) or weight-bearing (i.e., lateral lunge, dip test, standing hip abduction) positions. Macadam et al. (2015) reported that side-bridge with hip abduction exercise, also called "side plank" provokes the highest activity of gluteus medius; however, this exercise also needs a proper control of the trunk. For instance, mixed exercises could be also applied by using a band in a "side-bridge" position (Figure 19.4). A more recent review revealed that variations of the "hip hitch-pelvic drop" exercise are able to generate higher activity in both gluteus medius and minimus segments (Moore et al., 2020). If clinicians aim to focus on the gluteus minimus muscle, from a basic hip hitch–pelvic drop exercise, the patient can progress to a "lateral step-up" (Figure 19.5).

FIGURE 19.5
"Lateral step-up" on a box.

FIGURE 19.7
Single-leg bridge with knees flexed exercise.

FIGURE 19.6
Bilateral hip extension exercise (bridge) combined with hip abduction. A band can be used for resisting abduction.

FIGURE 19.8
The "barbell hip thrust" exercise.

The gluteus maximus muscle is targeted with hip extension (knees flexed for decreasing hamstring activity). Again, non-weight-bearing (e.g., double-leg bridge, frontal plank with bent leg hip extension) and weight-bearing (e.g., single-leg wall squat with other leg knee extended, front squat) exercises can be applied. First, clinicians must consider that at a fixed load, unilateral exercises, e.g., single-leg bridge-knees flexed (Figure 19.6), impose a higher relative intensity on the limb than the bilateral version of that exercise, e.g., double-leg bridge. Exercises provoking high-level activation of gluteus maximus include "step-up," "lateral step-up," "belt squat," "split squat," or "traditional lunge" (Neto et al., 2020). The review by Macadam and Feser (2019) concluded that hip extension combined with hip abduction (Figure 19.7) or external rotation resulted in higher activity of the gluteus maximus. It is also relevant to consider the synergestic role gluteus maximus plays with hamstring or erector spinae musculature; therefore, clinicians can constrain the exercise to target a specific muscle, e.g., during a bridge the gluteus maximus may be better addressed with a flexed knee, whereas hamstring demands go up as the knees are extended. The "barbell hip thrust" exercise (Figure 19.8) is a good option for increasing the load during bridge variations (Neto et al., 2019).

Hamstring Musculature

Exercise programs, including the Nordic hamstring exercise (NHE) (van Dyk et al., 2019) or other types of exercise (Vatovec et al., 2020), have been shown to improve architecture and strength in the hamstring musculature and may reduce the risk of hamstring injuries.

Towards the hinge side of the continuum for strengthening the posterior musculature of the lower quadrant (i.e., gluteus maximus, hamstrings, and erector spinae) is the "deadlift." Several variations of this exercise are proposed: regular deadlift (lifted from the floor with arms outside the thighs), Romanian deadlift (more hip dominant with a more limited ROM), or sumo deadlift (wide stance regular deadlift where the hands are between the thighs while lifting). The deadlift does a great job of developing the posterior chain; however, an interesting literature review found that activation of erector spinae and quadriceps muscles was higher than activation of the gluteus maximus and biceps femoris during deadlift exercises, but they urge caution in interpretation based on methodology issues (Martín-Fuentes et al., 2020).

For individuals looking to challenge the posterior chain in a more constrained exercise a "single-leg bridge" with knee flexed (see Figure 19.7) is a good starting point. Progression occurs by increasing the moment arm by extending the knee, adding load or adding a variation such as the "heel strike against ball exercise" (Figure 19.9).

FIGURE 19.9
The "heel strike against ball exercise." The subject can increase the speed and amplitude for increasing the difficulty of the exercise.

FIGURE 19.10
"The Arabesque". The patient can use a kettlebell for increasing the load.

Alternatively, a less constrained standing unilateral exercise such as the "Arabesque" can be progressively loaded as well (Figure 19.10).

Quadriceps Musculature

Progressive exercise training of the quadriceps muscle is frequently recommended for those with patellofemoral pain (Chapter 3), knee osteoarthritis (Chapter 4), patellar tendinopathy (Chapter 2), and after ACL reconstruction.

The "squat" falls on the right side of the hip hinge continuum by adding in the knee to the movement execution. The squat has a large number of variations which can increase or decrease the load on the knee extensor mechanism without change in the external load. For instance, performing a bilateral squat on a slight declination by placing a step under the heel increases the moment arm at the knee, which leads to more load on the knee extension complex (Figure 19.11). A "single-leg decline squat" constrains this movement by removing the ability to weight shift and also increases load assuming external load cannot be added. The load on the tissue can be decreased or increased by using the other lower extremity muscles and joints (Figure 19.12). Another squat variant is the "Spanish squat" (Figure 19.13), which constrains the motion to being almost predominantly at the knee (similar to a leg extension) (Basas et al., 2018). This is a great option for achieving high loads at the knee without the need for any external loads. Finally, squats can be performed in a "split" stance leading to significant control

FIGURE 19.11
Bilateral "squat" with a slight declination by placing a step behind the toes for increasing the load on the patellar tendon.

FIGURE 19.12
"Single-leg decline squat" with declination.

FIGURE 19.13
"Spanish" squat with a muscle belt.

FIGURE 19.14
The "sumo squat." The subject can use a kettlebell for increasing the load.

over the forces at the knee. Changes in the shin angle and trunk lean of the lead and trail limb will control whether the loads are focused or distributed between the front and rear knee. Contrary to popular belief, advice to keep the "knee behind the toes" is not at all supported and positive shin angles should be used during squats and its variants to focus torque at the knee (Hofmann et al., 2017; Schütz et al., 2014).

Adductor Musculature

Diminished strength on the adductor squeeze test is a feature of athletes with groin pain (Mosler et al., 2015). For the adductor muscles the "sumo squat" (Figure 19.14) and

FIGURE 19.15
“Isometric ball squeeze.” The subject performs an isometric contraction by squeezing their knees against the ball.

other squat variations are a minimally constrained method that significantly targets the adductor magnus. In contrast, a constrained exercise such as the “isometric ball squeeze” (Figure 19.15) allows the clinician to ensure that any overload is occurring in the adductor complex. The “Copenhagen adduction exercise” (Figure 19.16) is a way to achieve high intensity for the adductor musculature using only bodyweight and it has been shown to be effective for improving the adduction strength; however, due to its higher loads, a progressive approach should be used to avoid DOMS (Serner et al., 2014).

FIGURE 19.16
“Copenhagen adduction exercise.” A box or chair supports the ankle/knee and the individual supports himself on his elbow in a side plank position.

Conclusion

Exercise plays an important role in the management of hip and knee problems. This chapter has outlined some basic principles of exercise prescription that should be considered in the clinical setting. A comprehensive assessment is required to ensure safe and suitable prescription and progression. The exercise program demands must be matched to the clinical presentation based on the concepts of SAID and progressive overload. Clinicians may use the basic principles outlined in this chapter as a guide for exercise prescription to meet the needs of each individual with hip and knee pain problems.

References

Alfredson H, Pietilä T, Jonsson P, et al. Heavy-load eccentric calf muscle training for the treatment of chronic Achilles tendinosis. Am J Sports Med. 1998;26:360–6.

Andrade R, Pereira R, van Cingel R, et al. How should clinicians rehabilitate patients after ACL reconstruction? A systematic review of clinical practice guidelines (CPGs) with a focus on quality appraisal (AGREE II). Br J Sports Med. 2020;54:512–51.

Arampatzis A, Mersmann F, Bohm S. Individualized muscle-tendon assessment and training. Front Physiol. 2020;11:723.

Arden NK, Perry TA, Bannuru RR, et al. Non-surgical management of knee osteoarthritis: comparison of ESCEO and OARSI 2019 guidelines. Nat Rev Rheumatol. 2021;17:59–66.

Armes C, Standish-Hunt H, Androulakis-Korakakis P, et al. "Just One More Rep!" – Ability to predict proximity to task failure in resistance trained persons. Front Psychol. 2020;11:565416.

Bartholdy C, Juhl C, Christensen R, et al. The role of muscle strengthening in exercise therapy for knee osteoarthritis: A systematic review and meta-regression analysis of randomized trials. Semin Arthritis Rheum. 2017;47:9–21.

Basas A, Cook J, Gómez MA, et al. Effects of a strength protocol combined with electrical stimulation on patellar tendinopathy: 42 months retrospective follow-up on 6 high-level jumping athletes. Phys Ther Sport. 2018;34:105–12.

Bohm S, Mersmann F, Arampatzis A. Human tendon adaptation in response to mechanical loading: a systematic review and meta-analysis of exercise intervention studies on healthy adults. Sports Med Open. 2015;1:7.

Cibulka MT, Bloom NJ, Enseki KR, et al. Hip pain and mobility deficits-hip osteoarthritis: Revision 2017. J Orthop Sports Phys Ther. 2017;47:A1–A37.

Clifford C, Challoumas D, Paul L, et al. Effectiveness of isometric exercise in the management of tendinopathy: a systematic review and meta-analysis of randomised trials. BMJ Open Sport Exerc Med. 2020;6:e000760.

Clijsen R, Fuchs J, Taeymans J. Effectiveness of exercise therapy in treatment of patients with patellofemoral pain syndrome: systematic review and meta-analysis. Phys Ther. 2014;94:1697–708.

Daenen L, Varkey E, Kellmann M, Nijs J. Exercise, not to exercise, or how to exercise in patients with chronic pain? Applying science to practice. Clin J Pain. 2015;31:108–14.

Delmore RJ, Laudner KG, Torry MR. Adductor longus activation during common hip exercises. J Sport Rehabil. 2014;23:79–87.

Evans JW. Periodized resistance training for enhancing skeletal muscle hypertrophy and strength: A mini-review. *Front Physiol.* 2019;10:13.

Fletcher JS, Banasik JL. Exercise self-efficacy. Clin Excell Nurse Pract. 2001;5:134–43.

Franchi MV, Reeves ND, Narici MV. Skeletal muscle remodeling in response to eccentric vs. concentric loading: Morphological, molecular, and metabolic adaptations. Front Physiol. 2017;8:447.

Geneen LJ, Moore RA, Clarke C, et al. Physical activity and exercise for chronic pain in adults: an overview of Cochrane Reviews. Cochrane Database Syst Rev. 2017;4:CD011279.

Gérard R, Gojon L, Decleve P, Van Cant J. The effects of eccentric training on biceps femoris architecture and strength: A systematic review with meta-analysis. J Athl Train. 2020;55:501-14.

Haff G, Triplett NT. Essentials of Strength Training and Conditioning. NSCA; 2016.

Helms ER, Cronin J, Storey A, Zourdos MC. Application of the repetitions in reserve-based rating of perceived exertion scale for resistance training. Strength Cond J. 2016;38:42–9.

Herbert RD, de Noronha M, Kamper SJ. Stretching to prevent or reduce muscle soreness after exercise. Cochrane Database Syst Rev. 2011;7:CD004577.

Hofmann CL, Holyoak DT, Juris PM. Trunk and shank position influences patellofemoral joint stress in the lead and trail limbs during the forward lunge exercise. J Orthop Sports Phys Ther. 2017;47:31–40.

Houglum P. Therapeutic exercise for musculoskeletal injuries. Champaign, IL: Human Kinetics; 2005.

John D. Intervention. On Target Publications; 2013

Kiely J. Periodization paradigms in the 21st century: evidence-led or tradition-driven? Int J Sports Physiol Perform. 2012;7:242–50.

Knudson D. Fundamentals of Biomechanics. 2nd ed. Switzerland AG: Springer; 2007.

Konrad A, Močnik R, Titze S, et al. The influence of stretching the hip flexor muscles on performance parameters: A systematic review with meta-analysis. Int J Environ Res Public Health. 2021;18:1936.

Kraemer WJ, Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. Med Sci Sports Exerc. 2004;36:674-88.

Kubo K, Ikebukuro T, Yata H. Effects of squat training with different depths on lower limb muscle volumes. Eur J Appl Physiol. 2019;119:1933–42.

Lauersen JB, Bertelsen DM, Andersen LB. The effectiveness of exercise interventions to prevent sports injuries: a systematic review and meta-analysis of randomised controlled trials. Br J Sports Med. 2014;48:871–7.

Lauersen JB, Andersen TE, Andersen LB. Strength training as superior, dose-dependent and safe prevention of acute and overuse sports injuries: a systematic review, qualitative analysis and meta-analysis. Br J Sports Med. 2018;52:1557–63.

Lawrence MA, Carlson LA. Effects of an unstable load on force and muscle activation during a parallel back squat. J Strength Cond Res. 2015;29:2949–53.

Littlewood C, Bateman M, Brown K, et al. A self-managed single exercise programme versus usual physiotherapy treatment for rotator cuff tendinopathy: a randomised controlled trial (the SELF study). Clin Rehabil. 2016;30:686–96.

Logerstedt DS, Scalzitti DA, Bennell KL, et al. Knee pain and mobility impairments: Meniscal and articular cartilage lesions Revision 2018. J Orthop Sports Phys Ther. 2018;48:A1–A50.

Lorenz D, Morrison S. Current concepts in periodization of strength and conditioning for the sports physical therapist. Int J Sports Phys Ther. 2015;10:734–47.

Lovegrove S, Hughes LJ, Mansfield SK, et al. Repetitions in reserve is a reliable tool for prescribing resistance training load. J Strength Cond Res. 2021 Epub Ahead of Print.

Macadam P, Feser EH. Examination of gluteus maximus electromyographic excitation associated with dynamic hip extension during body weight exercise: A systematic review. Int J Sports Phys Ther. 2019;14:14–31.

Macadam P, Cronin J, Contreras B. An examination of the gluteal muscle activity associated with dynamic hip abduction and hip external rotation exercise: A systematic review. Int J Sports Phys Ther. 2015;10:573–91.

Martín-Fuentes I, Oliva-Lozano JM, Muyor JM. Electromyographic activity in deadlift exercise and its variants. A systematic review. PLoS One. 2020;15:e0229507.

Minshull C, Gleeson N. Considerations of the principles of resistance training in exercise studies for the management of knee osteoarthritis: A systematic review. Arch Phys Med Rehabil. 2017;98:1842–51.

Moore D, Semciw AI, Pizzari T. Systematic review and meta-analysis of common therapeutic exercises that generate highest muscle activity in the gluteus medius and gluteus minimus segments. Int J Sports Phys Ther. 2020;15:856–81.

Morawetz D, Blank C, Koller A, et al. Sex-related differences after a single bout of maximal eccentric exercise in response to acute effects: a systematic review and meta-analysis. J Strength Cond Res. 2020;34:2697–707.

Morrison S. Optimal Loading: ExRx for Rehabilitation Professionals. Professional Course; 2020.

Morrison S, Ward P, duManoir G. Energy system development and load management through the rehabilitation and return to play process. Int J Sports Phys Ther. 2017;12:697–710.

Mosler AB, Agricola R, Weir A, et al. Which factors differentiate athletes with hip/groin pain from those without? A systematic review with meta-analysis. Br J Sports Med. 2015;49:810.

Neto WK, Vieira TL, Gama EF. Barbell hip thrust, muscular activation and performance: A systematic review. J Sports Sci Med. 2019;18:198-206.

Neto WK, Soares EG, Vieira TL, et al. Gluteus maximus activation during common strength and hypertrophy exercises: A systematic review. J Sports Sci Med. 2020;19:195–203.

Nicolson PJA, Bennell KL, Dobson FL, et al. Interventions to increase adherence to therapeutic exercise in older adults with low back pain and/or hip/knee osteoarthritis: a systematic review and meta-analysis. Br J Sports Med. 2017;51:791–99.

O'Sullivan K, McAuliffe S, Deburca N. The effects of eccentric training on lower limb flexibility: a systematic review. Br J Sports Med. 2012;46:838–45.

Panariello RA, Stump TJ, Allen AA. Rehabilitation and return to play following anterior cruciate ligament reconstruction. Oper Techn Sport Med. 2017;25:181–93.

Plisk SS, Stone M H. Periodization strategies. *Strength Cond J .2003;*25:19–37.

Rio E, Kidgell D, Moseley GL, et al. Tendon neuroplastic training: changing the way we think about tendon rehabilitation: a narrative review. Br J Sports Med. 2016;50:209–15.

Saltychev M, Dutton RA, Laimi K, et al. Effectiveness of conservative treatment for patellofemoral pain syndrome: A systematic review and meta-analysis. J Rehabil Med. 2018;50:393–401.

Schoenfeld BJ, Ratamess NA, Peterson MD, et al. Effects of different volume-equated resistance training loading strategies on muscular adaptations in well-trained men. J Strength Cond Res. 2014;28:2909–18.

Schoenfeld BJ, Ogborn D, Krieger J. Dose-response relationship between weekly resistance training volume and increases in muscle mass: A systematic review and meta-analysis. J Sports Sci. 2017;35:1073–82.

Schoenfeld BJ, Grgic J, Krieger J. How many times per week should a muscle be trained to maximize muscle hypertrophy? A systematic review and meta-analysis of studies examining the effects of resistance training frequency. J Sports Sci. 2019;37:1286–95.

Schoenfeld BJ, Grgic J, Every DWV, Plotkin DL. Loading recommendations for muscle strength, hypertrophy, and local endurance: A re-examination of the repetition continuum. Sports. 2021;9:32.

Schütz P, List R, Zemp R, et al. Joint angles of the ankle, knee, and hip and loading conditions during split squats. J Appl Biomech. 2014;30:373-80.

Serner A, Jakobsen MD, Andersen LL, et al. EMG evaluation of hip adduction exercises for soccer players: implications for exercise selection in prevention and treatment of groin injuries. Br J Sports Med. 2014;48:1108–14.

Sigward SM, Chan MS, Lin P, et al. Compensatory strategies that reduce knee extensor demands during a bilateral squat change from 3 to 5 months following anterior cruciate ligament reconstruction. J Orthop Sports Phys Ther. 2018;48:713–18.

Silbernagel KG, Thomeé R, Thomeé P, et al. Eccentric overload training for patients with chronic Achilles tendon pain: a randomised controlled study with reliability testing of the evaluation methods. Scand J Med Sci Sports. 2001;11:197–206.

Smith BE, Hendrick P, Smith TO, et al. Should exercises be painful in the management of chronic musculoskeletal pain? A systematic review and meta-analysis. Br J Sports Med. 2017;51:1679–87.

Stanish WD, Rubinovich RM, Curwin S. Eccentric exercise in chronic tendinitis. Clin Orthop Relat Res. 1986:65–8.

Steele J, Endres A, Fisher J, et al. Ability to predict repetitions to momentary failure is not perfectly accurate, though improves with resistance training experience. Peer J. 2017;5:e4105.

Swart NM, van Oudenaarde K, Reijnierse M, et al. Effectiveness of exercise therapy for meniscal lesions in adults: A systematic review and meta-analysis. J Sci Med Sport. 2016;19:990-8.

Thomas E, Bianco A, Paoli A, Palma A. The relation between stretching typology and stretching duration: The effects on range of motion. Int J Sports Med. 2018;39:243–54.

Vaegter HB, Handberg G, Graven-Nielsen T. Similarities between exercise-induced hypoalgesia and conditioned pain modulation in humans. Pain. 2014;155:158–67.

van Dyk N, Behan FP, Whiteley R. Including the Nordic hamstring exercise in injury prevention programmes halves the rate of hamstring injuries: a systematic review and meta-analysis of 8459 athletes. Br J Sports Med. 2019;53:1362–70.

Vatovec R, Kozinc Ž, Šarabon N. Exercise interventions to prevent hamstring injuries in athletes: A systematic review and meta-analysis. Eur J Sport Sci. 2020;20:992–1004.

Vigotsky A, Bryanton M. Relative muscle contributions to net joint moments in the barbell back squat. American Society of Biomechanics 40th Annual Meeting. North Carolina State University, Raleigh, NC; 2016.

Wallis JA, Roddy L, Bottrell J, et al. A systematic review of Clinical Practice Guidelines for physical therapist management of patellofemoral pain. Phys Ther. 2021;101(3):pzab021.

Walsh ME, French HP, Wallace E, et al. Existing validated clinical prediction rules for predicting response to physio-therapy interventions for musculoskeletal conditions have limited clinical value: A systematic review. J Clin Epidemiol. 2021;135:90–102.

Weppler CH, Magnusson SP. Increasing muscle extensibility: A matter of increasing length or modifying sensation? Phys Ther. 2010;90:438–49.

Winters M, Holden S, Lura CB, et al. Comparative effectiveness of treatments for patellofemoral pain: a living systematic review with network meta-analysis. Br J Sports Med. 2020;55(7):369–77.

Yeung SS, Yeung EW, Gillespie LD. Interventions for preventing lower limb soft-tissue running injuries. Cochrane Database Syst Rev. 2011;7:CD001256.